TELESCOPE MAKING 6

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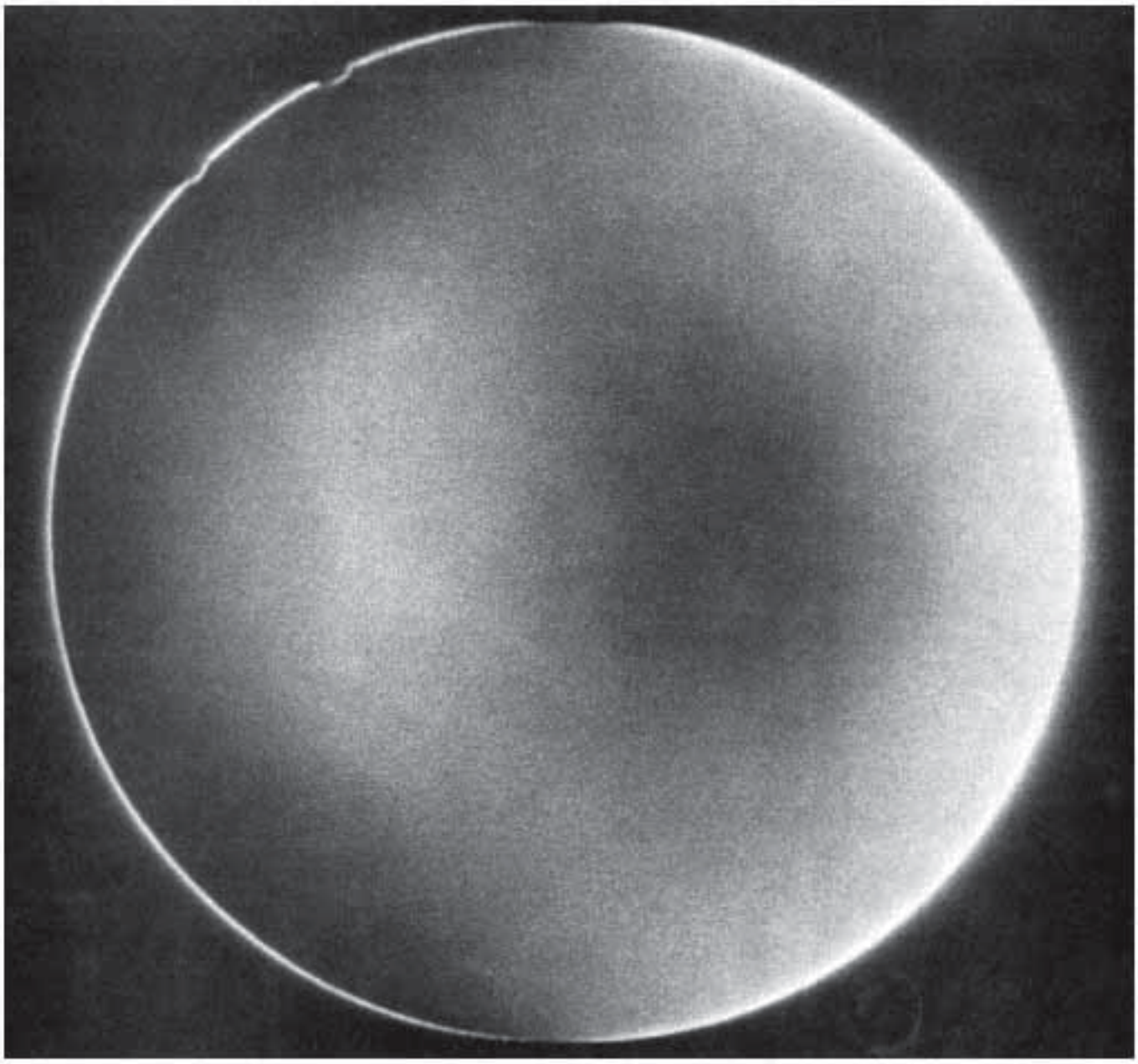
The magazine *for*, *by* and *about* telescope makers!

Winter 1979/80



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TELESCOPE MAKING

The magazine *for, by* and *about* telescope makers!

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Cover photo: Focogram of a 6" f/8 mirror made by Criterion Optical Company for their RV-6 Dynascope. To take the picture, a 200 mm telephoto lens was placed immediately behind the knife-edge, and a series of exposures made. See the article on page 25. Photo by R. Berry.

Editorial

At two large gatherings of telescope makers a new trend in judging has taken place: the "contest" has been removed. Yet those who wish to receive recognition, when it is merited, still do.

The prime reason for showing telescopes at meetings is that the good ideas embodied in their design may help some other person in the pursuit of the hobby of telescope making. So what the judges have done at these two meetings is abandon prizes and substitute awards of merit.

In the past 47 years, while belonging to astronomical societies and telescope making clubs, I've often heard the words, "I'm going to win first prize!", but I can't recall ever hearing the words "...to show something that might help other enthusiasts make better instruments."

Failure to win a "prize" causes anger and disappointment. It causes dissension, and worst of all, that angry person might not return or enter an exhibit at the next meeting. His ideas and skills will be lost.

Maybe such actions are childish and not worthy of sympathy, but why keep the situation that causes it in the first place?

Granted everyone likes recognition by their peers for an effort in any field — and rightly so. I don't think anyone (regardless of what they say) dislikes receiving an award for efforts expended. This is why two organizations (the Apollo Rendezvous and Telescope Fair in Dayton, Ohio, and the Riverside Telescope Makers Convention), starting in 1971 in Dayton and 1970 in Riverside, have no contest. Instead they award Certificates of Merit to outstanding exhibits.

Merit awards remove the biases inherent in prize rankings. Consider the fairness of the merit award method of

appraising as shown by the following example: Two persons exhibit. Mr. A has an instrument of the highest mechanical and optical standards (due to either his workshop and skills or the money he invested in professional parts) with no new ideas, but stunning execution. Mr. B has a low-budget telescope made with inexpensive parts, but he has employed an ingenious approach to making a telescope with fine handling characteristics at a minimum expense, using pipes.

In a contest situation, Mr. A would get first prize and, if he is lucky, Mr. B would get an honorable mention. However much Mr. A's telescope is the TM's dream machine, it is doubtful if another as fine will be built by anyone attending the meeting. Mr. B's practical telescope, and its many important and simple ideas, will be copied in other instruments when the meeting delegates return home. On the basis of which instrument offers other TMs the greatest amount of useful information, one must concede that Mr. B's is more important.

Yet in view of A's fine workmanship, it seems hardly fair to give recognition to B and not to him. The fair way is to give EQUAL recognition to both men with a Certificate of Merit for exhibiting their instruments for the benefit of those attending! This method of making everyone equal by process of their contribution to amateur telescope making is the one fair and practical way to handle exhibits at meetings.

I have had the privilege of being an evaluator of exhibits at both Riverside and Dayton, and I am familiar with the method and results of this approach. (Only once have I heard a protest at one of these meetings — and that was when one person, whose excellent optics might well have been selected for an award, protested the fact that we called off appraising optical performance due to poor seeing that night.)

I would like to extend my personal congratulations to Clifford Holmes and his officers of the Riverside Society and to Roger Hoefer and the officers of the Miami Valley Astronomical Society for their efforts in eliminating contests in the appraising of exhibits at their meetings.

I hope that the organizers of other meetings will realize the merits of not holding contests. And I hope, sincerely, that they will change their award system meetings to eliminate ranked prize contest judging.

Come on TMs! Let's make 1980 the year in which all hobbyists are declared equal in efforts to help others by exhibiting at your meetings and put our hobby on its highest level of personal recognition of its members.

Robert E. Cox
Associate Editor
TELESCOPE MAKING

Letters

Step One

Dear Mr. Berry / I was disappointed that TM#5 did not have the articles on mirror grinding, polishing, and testing, since I have purchased a mirror kit and I'm waiting for instructions.

I liked TM#4 and TM#5, but they were the same to me: I'll have use for them in the future.

Duane C. Gerling
1706 Mt. Pleasant St.
Burlington, IA 52601

Dear Mr. Gerling / Sorry we've disappointed you, but material on mirror making has been very slow to come in — much slower than we had hoped. Nor, as you will see by looking at this issue, are there complete instructions for mirror-making in this issue. TM is a supplement to the the standard literature on mirror making, rather than a how-to course. We recommend that you purchase one or more of the following books for basic mirror-making instructions:
All About Telescopes, *by Sam Brown;* **How to Make a Telescope**, *by Jean Texereau;* **The Standard Handbook for Telescope Making**, *by N.E. Howard; or* **Making Your Own Telescope**, *by Allyn J. Thompson.*

Brazilian TM

Dear Sirs / Reporting back to my letter of last March 5th, where I told you I would import

from Germany a blank of optical glass Duran 50 FTRS, 8330 — well, the glass arrived at my home in less than 100 days. The picture shows the box and the blank measuring 410 x 80 mm, weighing 22 kgs.

Now all I have to do is start grinding. I am afraid, but I will cross my fingers and next month do it. Next year I hope to send you some pictures. My observatory is ready, that is, only the sliding roof must be finished yet.

I will let you know as the job progresses (or regresses).

Nevio Tognato
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S. Bernardo do Campo 09.700
S. Paulo, Brazil

45➤

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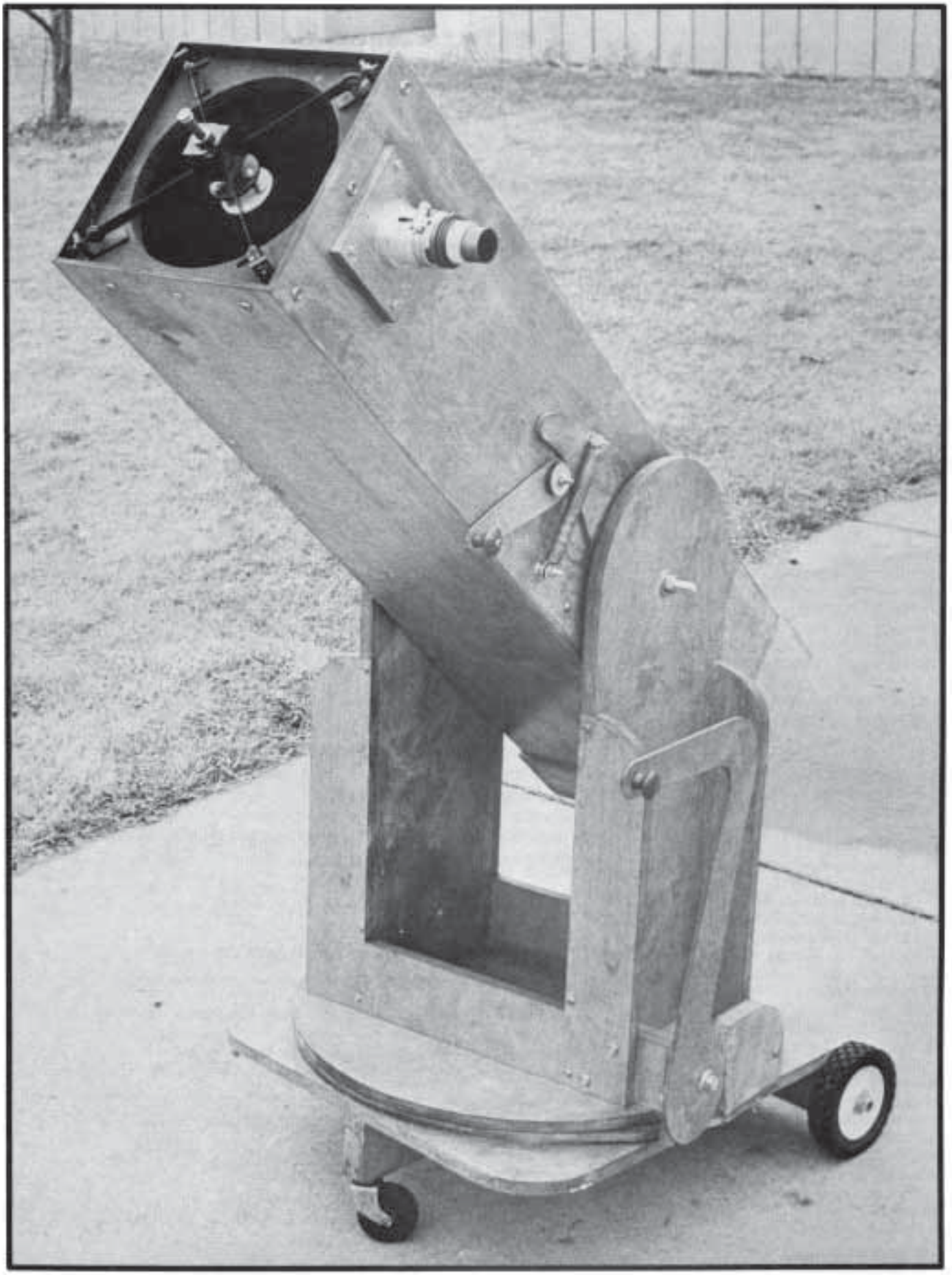


the serious beginner's

Basic 8" Scope

Most of us have seen various telescope projects that have appeared in the "Popular Fix-It-Up" style magazine. They usually feature a list of Edmund or Jaegers parts (such as a 2-inch lens with a 50" focal length) supported on a strap-iron alt-azimuth mount and tripod. They're undermounted, wobbly, and generally limit the elevation range of the telescope to 0° through 45°!

After seeing one of these projects about five years ago, I resolved to design and build a better beginner's scope. It would have the following features:

1. It would be an 8-inch f/6 Newtonian.
2. The mount would be an alt-azimuth, but convertible to equatorial.
3. The structure would be mostly of wood, for ease of construction.
4. The telescope and mount would be one compact unit no more than six feet long.
5. The telescope would be easy to use, with slow-motion controls on both axes, and a convenient eye-piece position.

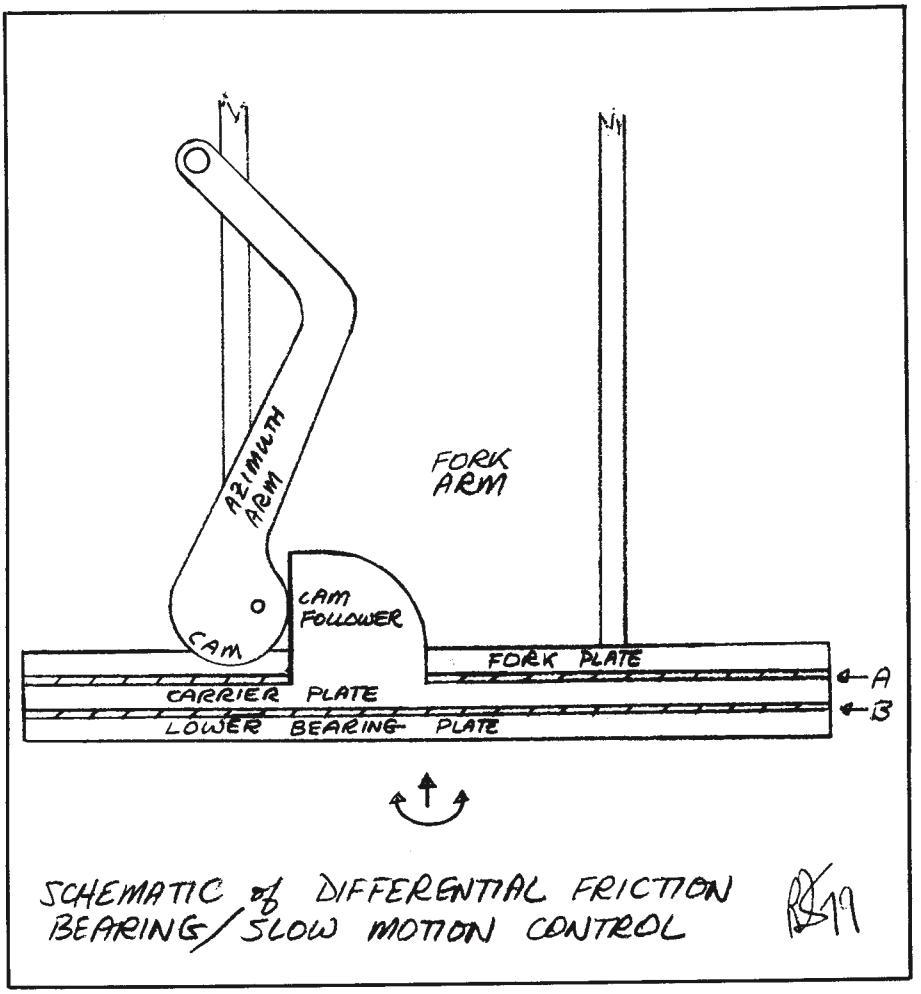
I reviewed several mounting schemes and finally settled on a variant of the Dobson telescope which is the simplest, most stable way I know of making an altazimuth telescope. However, I chose a double bearing system for each axis, which allowed me to integrate a slip-clutch into the bearing.

The telescope tube is basic box construction, with the center and end pieces being ¾" plywood. Since I was living on the East Coast when I made this scope, I was able to obtain some outstanding Russian and Finnish plywood at several of the "home improvement centers" in my area. (No luck out here in Smogville, CA, finding such fine material.)

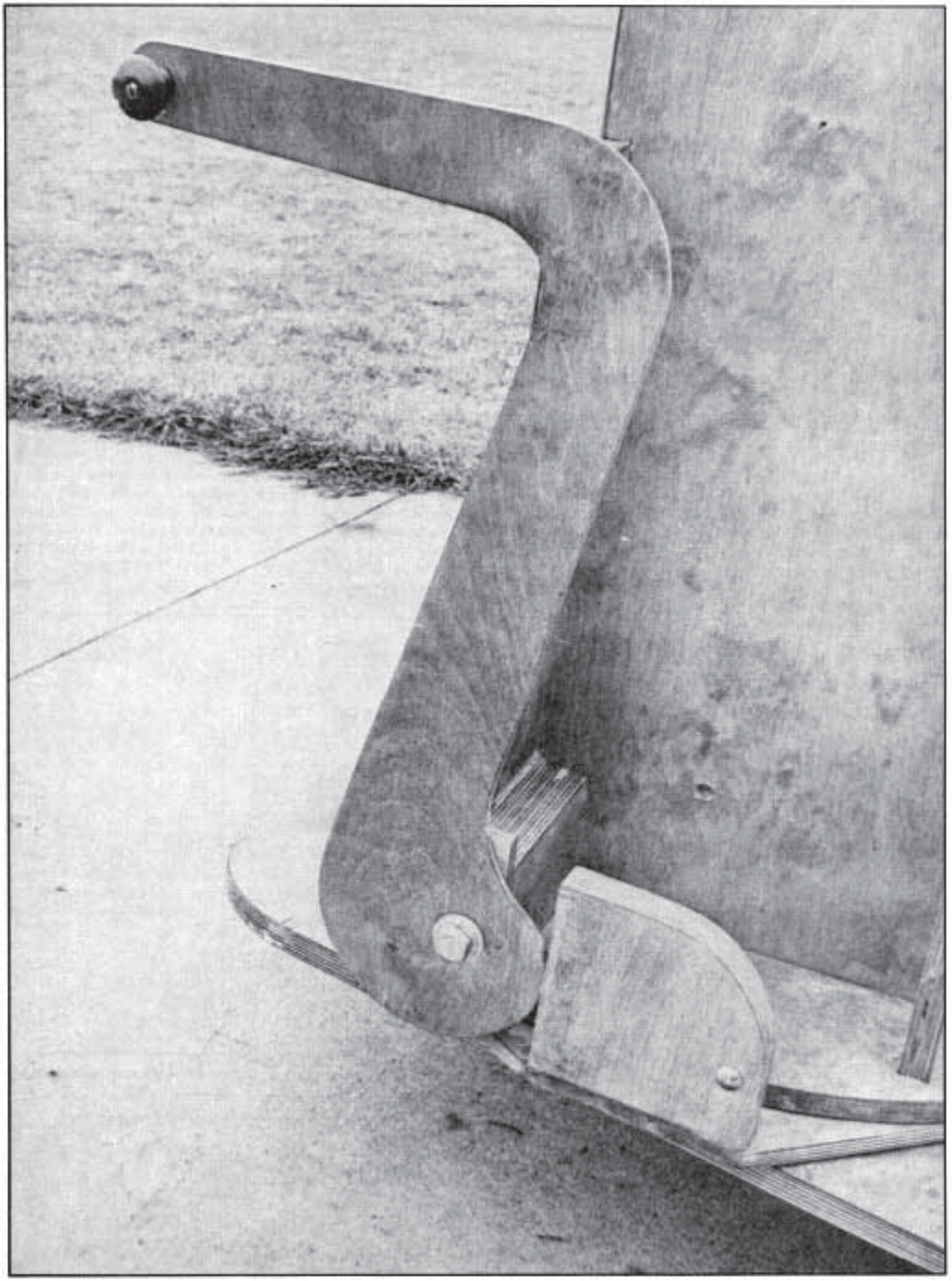
I used glue and screw construction throughout, doing much of the clamping on a "Work-Mate" portable workbench. These are great gadgets, by the way, but nothing more than a pair of right-angle gluing clamps is absolutely necessary for assembling the telescope.

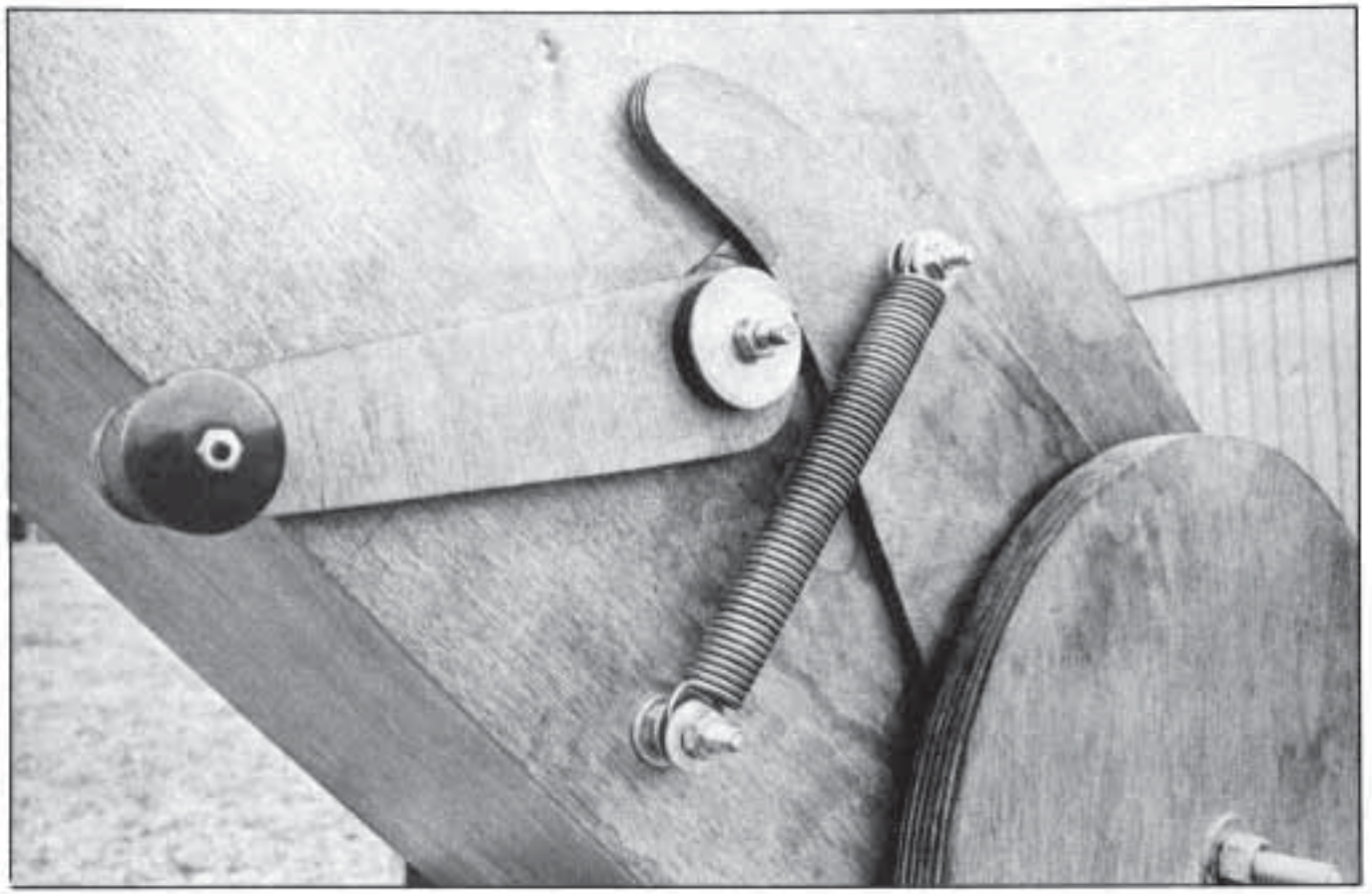
The mirror mount is a little unusual. A piece of ¾" plywood is spring-loaded to the backplate of the tube to allow collimation. The mirror rests on top of a layer of "bubble wrap" plastic packaging material, which provides a semi-flotation support. Lateral support is provided by three metal corner braces attached to the back of the mirror/bubble-wrap plate. I then wrapped electrician's rubber tape around the three corner braces and the edge of the mirror to hold it in place.

The secondary support is standard, being adjustable for angle and along the optical axis. I cut the 45° mount for the



SCHEMATIC of DIFFERENTIAL FRICTION BEARING/SLOW MOTION CONTROL





diagonal from ABS plastic pipe and taped the diagonal to it with electrician's tape. Although you may scoff at the use of tape, it does hold. Several Newtonians I built ten years ago have their original diagonals, held by tape, and none has fallen out yet!

No finder was included in the design, because I've been content to sight down the tube of most of the telescopes I've owned. This method will usually get what I want to see within the field of a low-power eyepiece.

The mount is the really interesting part. In azimuth it's really two bearings on top of one another. Here's how it works: Bearing surface B (labeled in the diagram) is two disks of smooth plastic, one glued to the base plate and the other glued to the carrier (or fork-arm) plate. The telescope turns on this bearing when it's being slewed.

Bearing surface A has a lower coefficient of friction than does surface B. It's made of large teflon pads turning on smooth plastic. The telescope turns on surface A when the cam-and-follower control is used.

The cam-and-arm used for slow motion is attached to the fork with another plastic bearing allowing smooth turning. Under the nut which holds the assembly together is a large rubber grommet. When the nut is tightened, the rubber is squeezed enough so cam-and-arm turns smoothly but won't slip under the force of the spring which holds the cam follower against the cam. (The tension spring is attached behind the cam follower as seen in the drawing.) You've probably figured out that moving the azimuth arm to the left results in the telescope moving to the left, turning on bearing surface A.

A note on bearing materials: I've used the venerable formica "sink cut-out" for this type bearing, and it works well. For this particular design, however, I used disks cut from translucent plastic panels sold as diffusers for recessed fluorescent light fixtures. It's easy stuff to cut; I used a pair of shears.

Anyway, whatever you do for this type bearing, don't use ball bearings or any kind of bearing such as those in "lazy susan" rotating platforms. Telescopes don't need to turn frictionlessly. You'll end up with a telescope that turns in the wind!

Now a word about ergometrics: I designed this telescope to be used while seated. Thus, the controls are just below and to the right of the eyepiece. The cams were cut so that the telescope moves in the direction the control arm is moved. You may wish to alter this arrangement so that moving the control arm in a certain direction results in the object being observed moving in that direction. I didn't think of it, so I didn't do it!

I tried to sell this design to the editor of "Popular Fixitup," and even took it to their editorial offices in New York while on a business trip, but I was told that "it's beautiful, but it's too big!" (All of this ensued after I had rolled it down 57th Avenue and into the elevator of their building! The cop on the street was sure it was some sort of weapon, but a quick look at a stop light half a mile down the street dispelled his fears.)

I finally sold the telescope to the Science Department at Neil Armstrong Junior High School, Jacksonville, Illinois. It seems to be enjoying its stay there, especially, I am told, being rolled out into the parking lot on many clear days to project images of sunspots. Several copies have already been made, which I find very flattering.

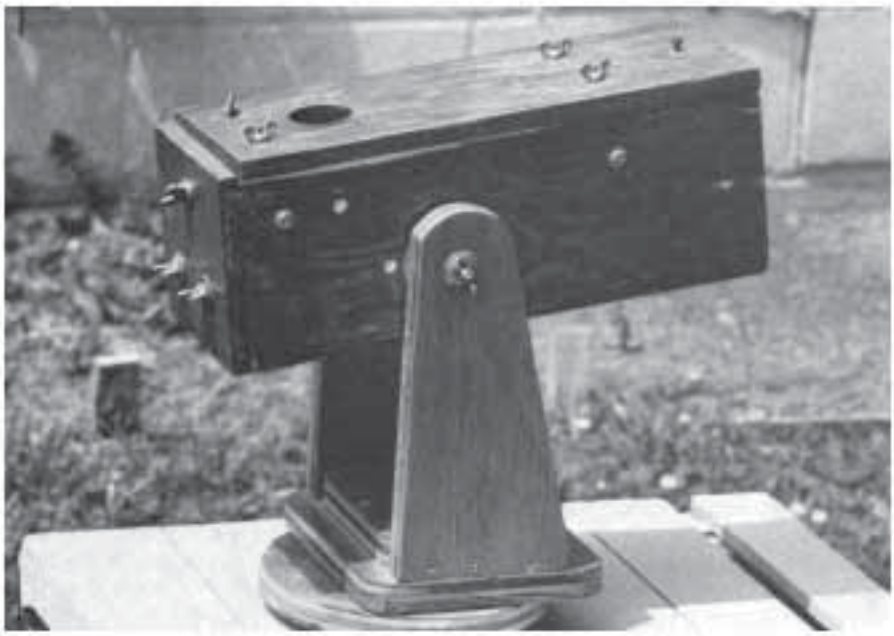
Although I don't view this design as the ultimate in basic telescope design, it does appear to be, in my modest opinion, a good start. I especially like being able to make subtle positional changes without having to shove the tube around manually. If anyone reading this uses this design or a variant, I'd appreciate having a snapshot of it.* I will of course answer any questions sent to me.

Richard Shaffer
2354 N. Canyada Ave.
Altadena, CA 91001

*Ed. Note: So would TM!

■

Two Tiny Multi-Purpose Telescopes



Even the best optics housed in a long tube on a marginal and awkward mounting can discourage your enthusiasm to get outside and look at the night sky. Sometimes just the physical effort of moving and setting up a heavy telescope, not to mention the fatiguing positions you must assume in order to view an object, often proves sufficient reason for letting an otherwise good telescope quietly gather dust in a corner of the house. To compound the problem, finding an object in a narrow-field instrument can often prove an exasperating experience, especially for a beginner.

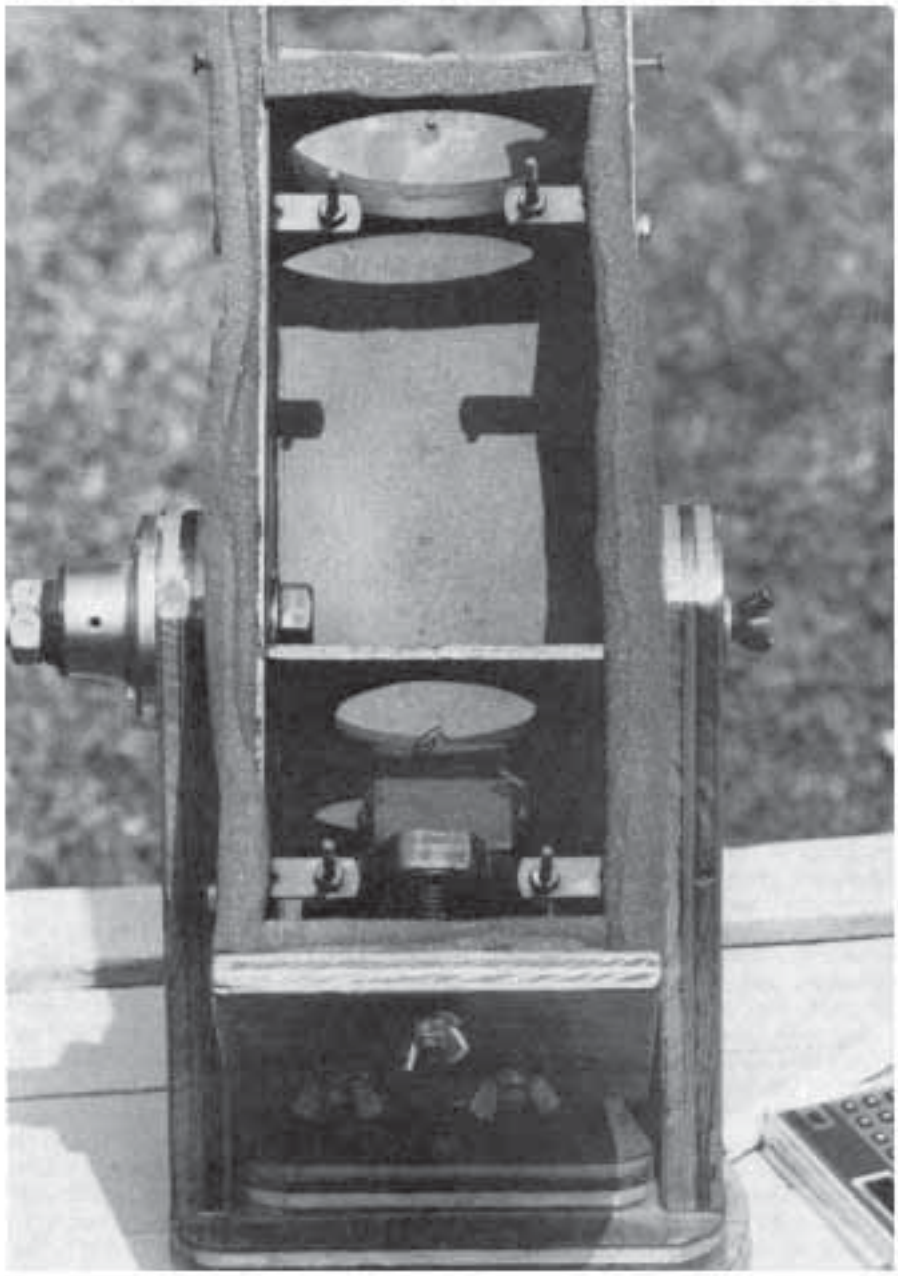
What I built as a solution is a small, light-weight, easy-to-use instrument which can be assembled by anyone in a home workshop for an approximate total cost of $100.00. There is nothing more complicated in building it than drilling holes or cutting a straight line in wood.

The scope is a 3" f/5 refractor. It has a high-quality secondary mirror to give a short tube and comfortable viewing position. It's on a simple mount which can be set up on a table top or camera tripod. Sitting comfortably relaxed in a chair, with a star chart spread out at my elbow, viewing is relaxing and enjoyable with it.

The image is right-side-up but reversed left-to-right, which is no more difficult to get used to than the standard inverted image. The wide field of view means that the scope acts as its own finder. There is no problem with vibration or temperature calibration of the telescope. Of course, if the clouds roll in, I simply pick it up and carry it back into the house under one arm.

Prior to beginning construction, make a full-size drawing showing the light cone converging to a ¾" image plane. The focal length is checked by taping the lens to a straight-edge, pointing it at the Sun.

Add the height of the focusing mount,



racked half-way in, to the radius of the tube or box along with the thickness of the tube to calculate the distance from the lens to the diagonal mirror. Glare-stops are drawn in, being sure the holes in them are slightly oversize to avoid losing light. Glare-stops can be cut from heavy cardboard or sheet balsa wood.

I mounted the diagonal mirror on a 45° wood block with double-sided tape and lightly epoxied the edge to prevent movement. The block was then glued to a circular plywood disk which in turn was mounted in the end plate using small bolts with compression springs and wing nuts for collimation.

If you choose to mount the optics in a plywood box, make one side removable or hinged to facilitate construction. Glue the edges, and use screws or small nails to insure rigidity. The cut-out for the eyepiece focuser can be cut with a drill hole attachment or a keyhole saw. Do this after the diagonal mirror is in place so it can be centered.

The lens cell in both versions was permanently held in place with three set screws, collimation effected by adjusting the diagonal mirror.

All internal structures of the tube should be sprayed flat black to prevent glare, including all exposed hardware.

I built a fork mounting out of plywood, using bolts and wing nuts for the axes. It is so simple that you can proceed, on the basis of the pictures alone, to design your own sturdy table-top mounting.

To take full advantage of the wide-field capabilities of this scope, I use a 32 mm Brandon ocular for viewing deep-sky objects, but for lunar or planetary work, a Barlow lens and/or higher power oculars can be used.

When I became interested in astrophotography, I remounted the optics in an aluminum tube. I then purchased a Meade mounting for a 3" refractor which I modified by having the declination axis shortened and threaded so the entire scope would balance with 35 mm cameras mounted on the cradle and declination axis.

I also shortened the manual grinding cables to allow comfortable use while seated. For traveling, I made a set of accessory tripod legs which pack neatly into a small suitcase with the disassembled telescope and mount. This allows me to take my entire "observatory" as carry-on luggage on commercial airline flights.

Since vacation sites usually have dark skies, I routinely take the telescope along. You only have to remember to plan all trips after the full moon!

Howard Lazerson
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Suite 1115
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■

the easy easel equatorial mount for a 4" RFT

As a planetarium lecturer and sponsor of the Escambia Amateur Astronomer's Association, I'm frequently asked to recommend a low-cost starter telescope. If a beginning stargazer already has a pair of binoculars, the locally available commercial scopes are not very suitable. While 50 and 60 mm refractors can give pleasing views of the Moon and planets, their balky alt-azimuth mounts are hard for beginners to use, particularly with the high-power, narrow-field-of-view Huygens eyepieces always provided with such scopes. What is needed is an easily assembled, properly mounted, high performance scope for less than $100.

Lately I've been recommending Coulter Optical's 4¼" RFT kit, which includes primary and secondary mirrors, diagonal mount, drawtube focuser, and tube ($27.50 ppd.). Recently American Science Center has been selling a fine set of four Kellner and Orthoscopic eyepieces for only $27.50. By good fortune, these eyepieces were intended for a spotting scope with a focal length of 450 mm, so the engraved powers (15x, 30x, 40x and 60x) are essentially correct for the RFT, and they provide the ideal range of magnifications to be used with it. The eyepieces are of fine quality, with wide fields. With 1.20" o.d., they can be adapted to standard 1¼" size with a few turns of electrical tape.

Actual assembly of the 4¼" RFT is no problem, and, in fact, ten E.A.A.A. members have already assembled these RFTs. Usually the construction takes about three hours, with about $5 extra expense for wood and small hardware items. Coulter provides assembly instructions with the kit.

An important advantage of this scope for beginners is that with the 27 mm Kellner (15x), the scope can be immediately used without any mount. Handheld, it provides spectacular views of the Moon, star fields in the Milky Way, and (properly filtered) the Sun. Excellent photos of the February 26 eclipse were made with such instruments.

If a sturdy photo tripod is available, the next step is to build a rotating tube cradle to mount your scope to it. My own experience with younger observers makes me believe the ability to rotate the tube on Newtonian telescopes is vital to observer comfort. (Besides, I got tired of having to pick up little kids!).

Dr. John Oliver (co-author of "Look Who's Moving into Our Neighborhood," April 1979 ASTRONOMY) suggested a very practical "door spring" cradle to me. This saddle-cradle design allows for easy rotation of the tube while keeping the object in the field of view at low powers. The cradle can be mounted directly on the photo tripod with a ¼" nut, and it can be used later as the declination arm of the equatorial mount by passing a ¼" bolt through the same hole.

In the table, you'll find a list of all parts of the mount, with the cradle parts listed first.

The cradle is 10" long and has two curved saddles at each end. They are lined with felt to prevent scratching the tube. Wood screws can be used to attach the saddle pieces to the cradle. The saddle pieces must be cut to match the curve of the 5" o.d. tube; for this a sabre saw works well. The screen door spring's tension holds the tube firmly against the curved saddles. The spring is attached to the cradle with cup hooks on diagonally opposite ends.

When used on a photo tripod, the RFT can now be used with 30x and 40x eyepieces. No finder is needed: the observer can just sight along the side of the tube while using the low power eyepiece.

To use the 60x eyepiece or have a group observing session, however, an equatorial mount with slow motion is necessary. Commercial mounts start at $50 and are much heavier than really required to support the RFT. To overcome this problem, I designed the "easy easel equatorial" mount specifically for the small RFT. While I have used this mount with my 3" f/8 refractor successfully at 100x, I do not recommend this mount for heavier or longer telescopes.

The photos provide a good overall view of the completed mount. The sizes of the tripod legs given in the table are for a 60" tall observer (a typical 12-year-old). For taller observers, lengthen the legs accordingly. Remember that if the primary user is a shorter child, it will be relatively easy to add leg extensions; also, it's easier for an adult to bend over slightly than to "boost" up a child to the eyepiece. ➤

The easel must be tilted at an angle equal to the observer's latitude for accurate equatorial tracking. Keep checking this angle during assembly, using a protractor and plumb bob.

First assemble the fork (actually a half fork, similar to the Quantum in design, if not elegance). Be sure to pre-drill the screw holes for the three long narrow screws which join the side and base of the fork. Small nails will help keep the two pieces perpendicular during assembly.

About 1" below the top center of the fork side, drill a ¼" hole for the declination axis bolt. Pass the bolt through the telescope side of the cradle and fork, and fasten it with a bumper washer and wing nut.

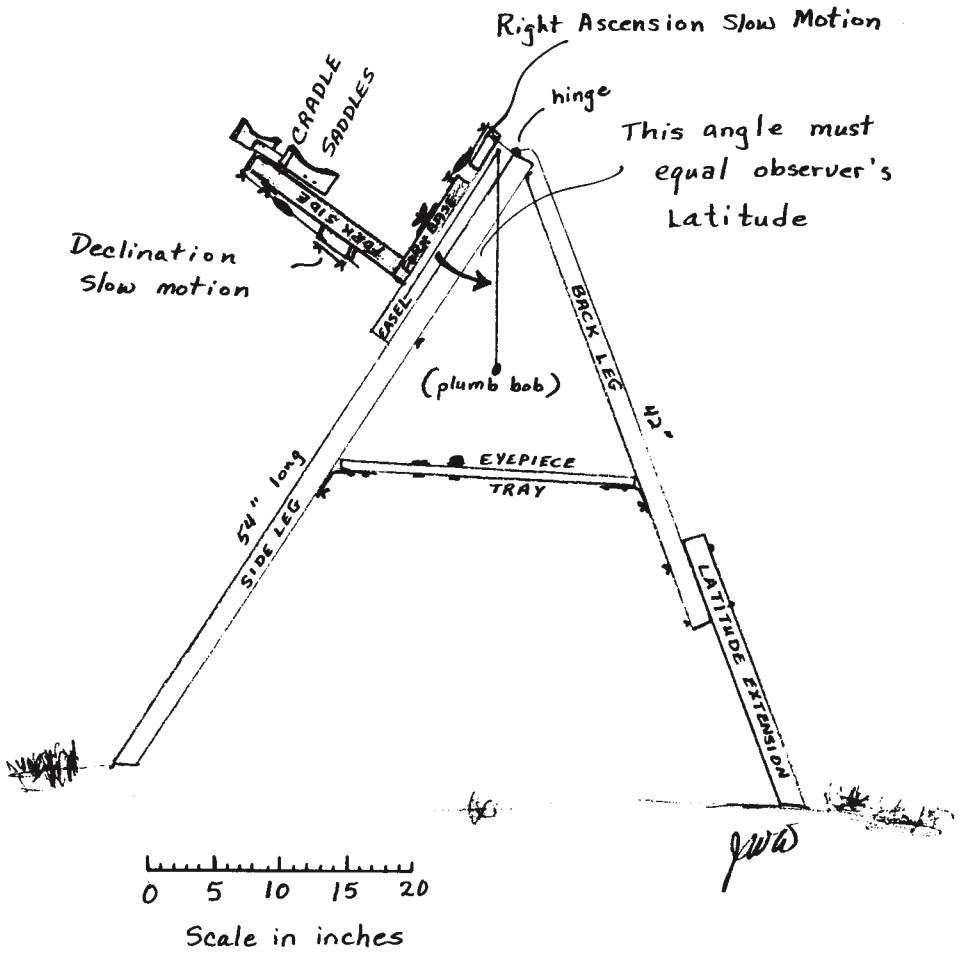
For smoother rotation, I devised a set of simple and inexpensive bearings. Make two pairs of 1½" diameter plastic washers (cut from margarine dish lids) with ¼" holes in their centers. Vaseline made a fine lubricant between each washer. One pair goes between the cradle and fork, the other between the fork and bumper washer. The rotation of the declination axis is "butter smooth," with tension adjusted by tightening the wing nut.

The declination axis has an optional rapid and slow-motion control arm. The pivoting of the arm provides rapid adjustment, while rotating the turnbuckle allows a much finer adjustment. To assemble, drill a 3/16" hole about 1" from the eyepiece end of the cradle. Screw a 10-32 x 2½" bolt all the way through the scope side of the cradle, and tighten a nut on the other side to secure the bolt firmly to the cradle.

Screw on a second nut above the first, leaving about ½" of bolt at the top; slip the loop at one end of the turnbuckle over the bolt, and tighten in place with a wing nut. This is the fixed part of the slow motion. The long threaded rod (or cut-off bolt) at the other end of the turnbuckle will be "sandwiched" between the two plates of the pivoting slow motion arm.

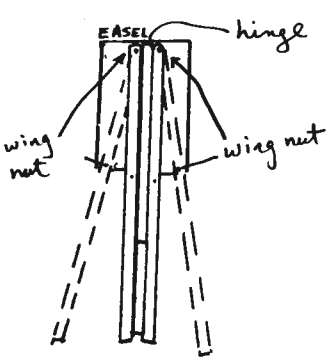
The two 5" long plates are drilled and bolted together, with one bolt, 2½" long, passing through a hole in the center of the fork side and through both plates; it is tightened with a wing nut. The other bolt is 1½" long and is countersunk into the bottom plate; its end pivots. Again a wing nut on the bolt controls how tightly the two plates are fixed together. The long rod of the turnbuckle is placed between the two plates.

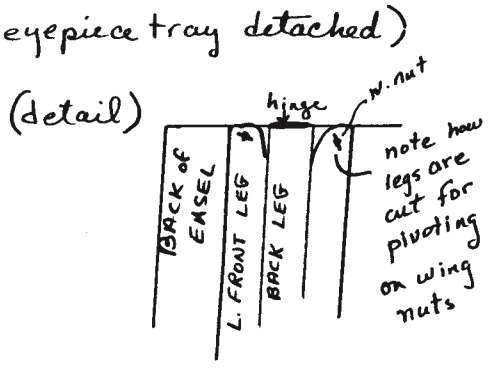
When both wing nuts are loosely clamped, the whole arm pivots and moves the declination cradle rapidly. Clamping the wing nuts tightly holds both rod and arm fixed; turning the turnbuckle gives the observer a precise

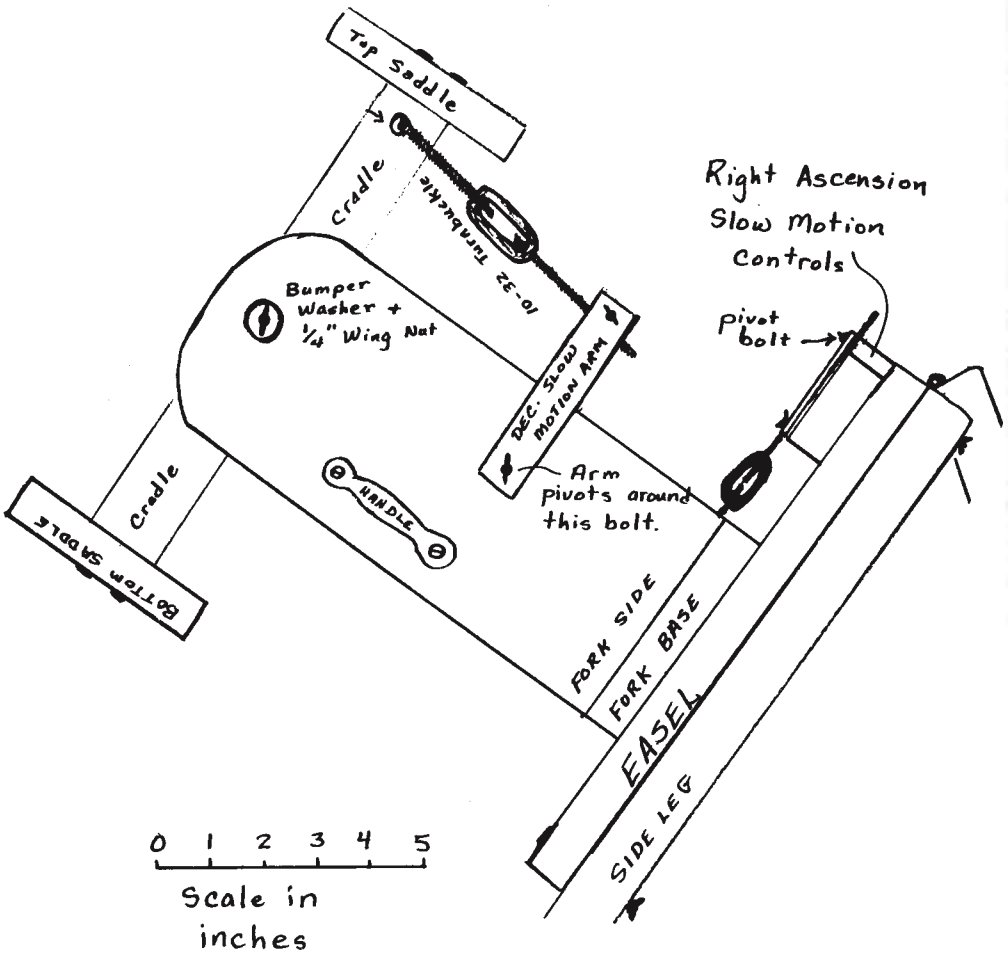


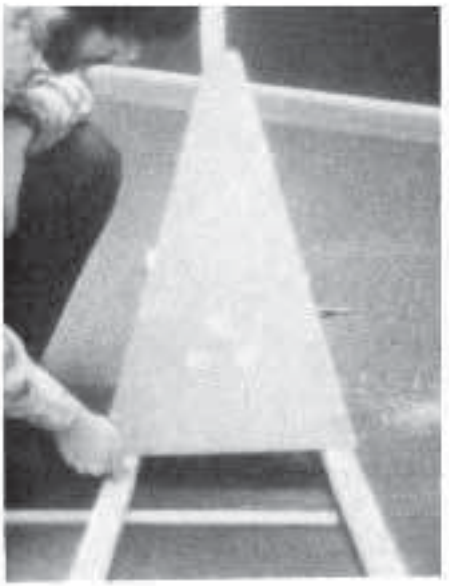
slow motion. The same system is used with the right ascension slow motions on the easel and fork base. You can add a carrying handle to the side of the fork opposite the slow motion arm; it doesn't interfere with operation.

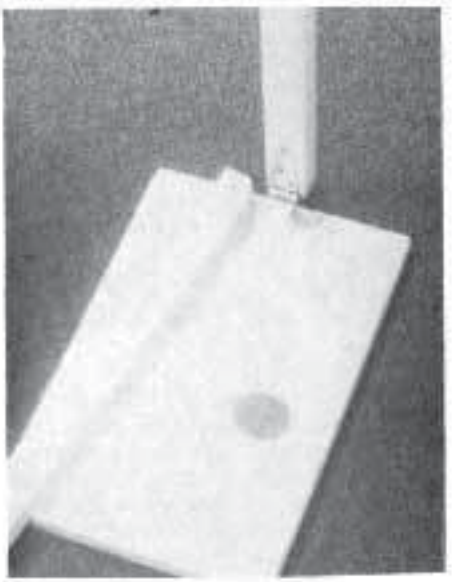
The easel tripod itself must be assembled next. First attach the back leg to the top of the easel with a small door hinge, using wood screws. Before drilling the holes at the top and bottom of the easel for the side legs, lay them out beside the center leg and be sure to note the clearance needed when the legs are folded in for compact carrying. I cut off part of the top inside portion of each leg for ease in folding. With the legs in place, drill the holes and insert the 10-32 X 2½" bolts, with the wing nuts behind the easel. When the two bottom wing nuts are tightened, the side legs are fixed open with a leg spread of about 24"; there is little chance of the tripod being easily toppled. Removing the bottom bolts











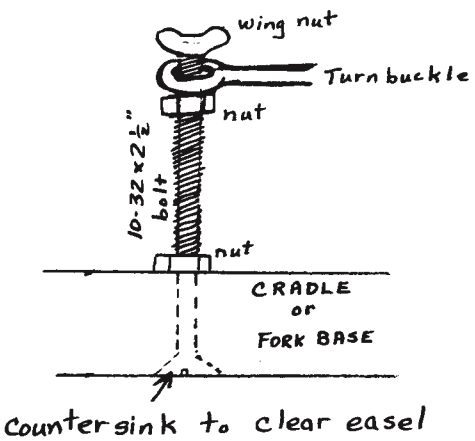
allows the legs to be folded compactly.

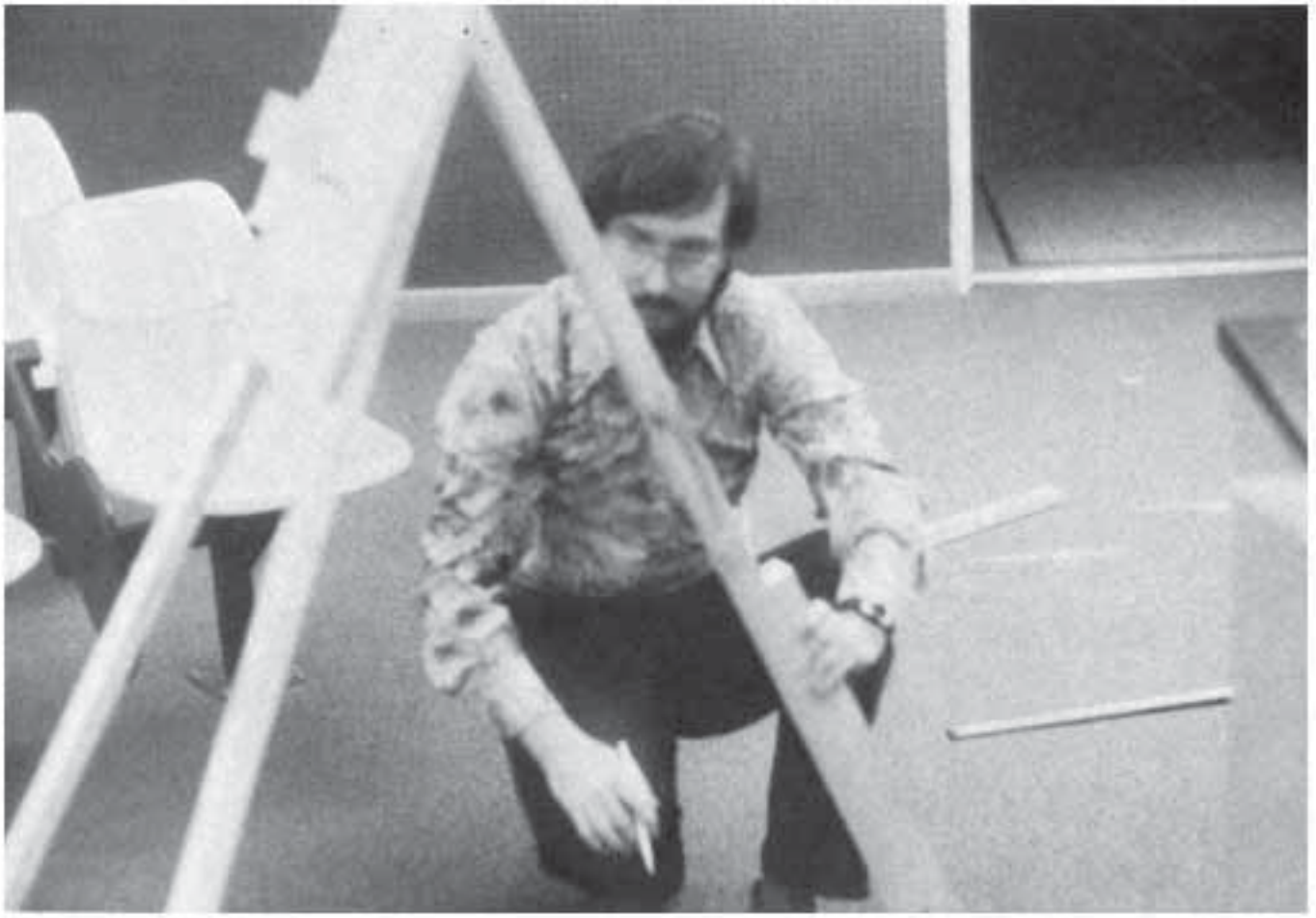
The eyepiece tray is really the key to the tripod's stability. Cut an isosceles triangle with base 15" and height 22", and square off the apex slightly. Attach metal corner brackets to it and bend the brackets to match the tilt of the tripod legs. Wood screws permanently attach the brackets to the bottom of the eyepiece tray, while bolts through the legs allow you to attach the brackets to the legs with wing nuts. These wing nuts are easily removed to take off the tray and fold the legs together.

Make holes in the tray with a 1¼" hole cutter for extra eyepieces, and add a wood lip to the tray's sides to prevent accessories from rolling off the tray.

With the back leg bolted in place, next consider the length of the latitude extension. Use the protractor and plumb bob (as shown in the photographs) while holding the extension. Once you have the correct length for your latitude angle, attach the extension with two long bolts. If you move to another latitude, only the position of this extension need be altered. The design is practical anywhere in the United States, and actually will be more stable at higher latitudes than it is here in Florida. (Nevertheless, I've had no balance problems with it at latitude 30°.)

Now attach the fork assembly to the easel. In the center of the fork base and center of the easel, drill a ⅜" hole for the large carriage bolt and hammer it into the back of the easel. Use four 4"-diameter margarine lids for bearings just as you did with the declination axis. Assemble the fork and easel and test for smooth



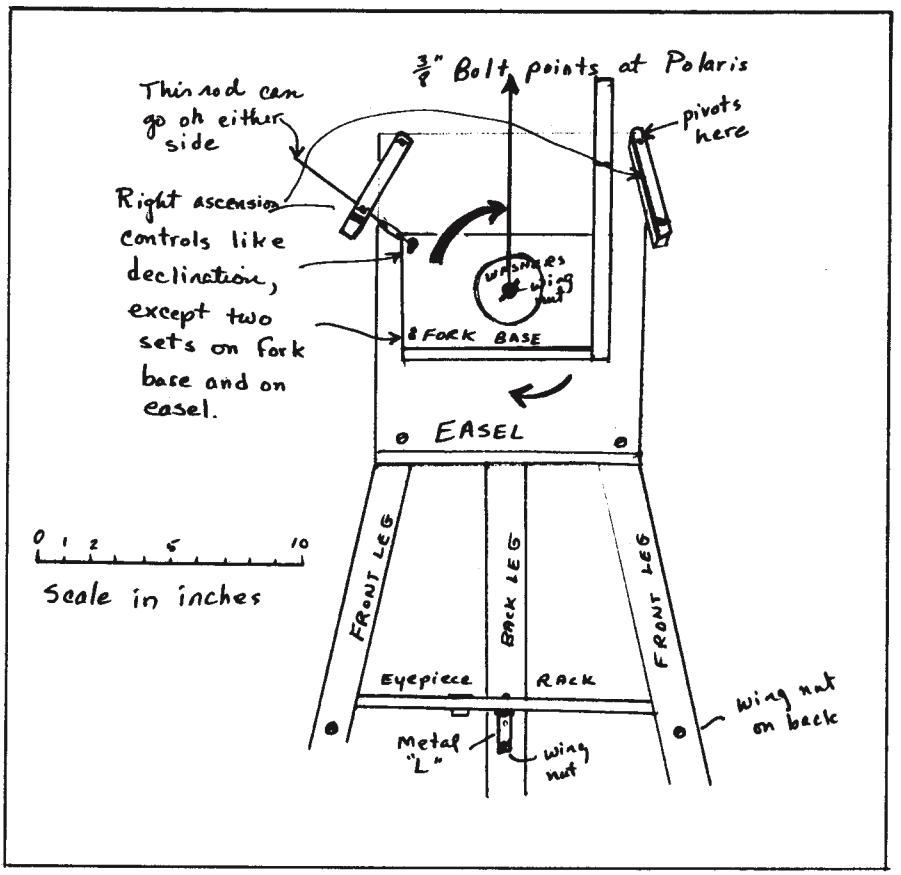


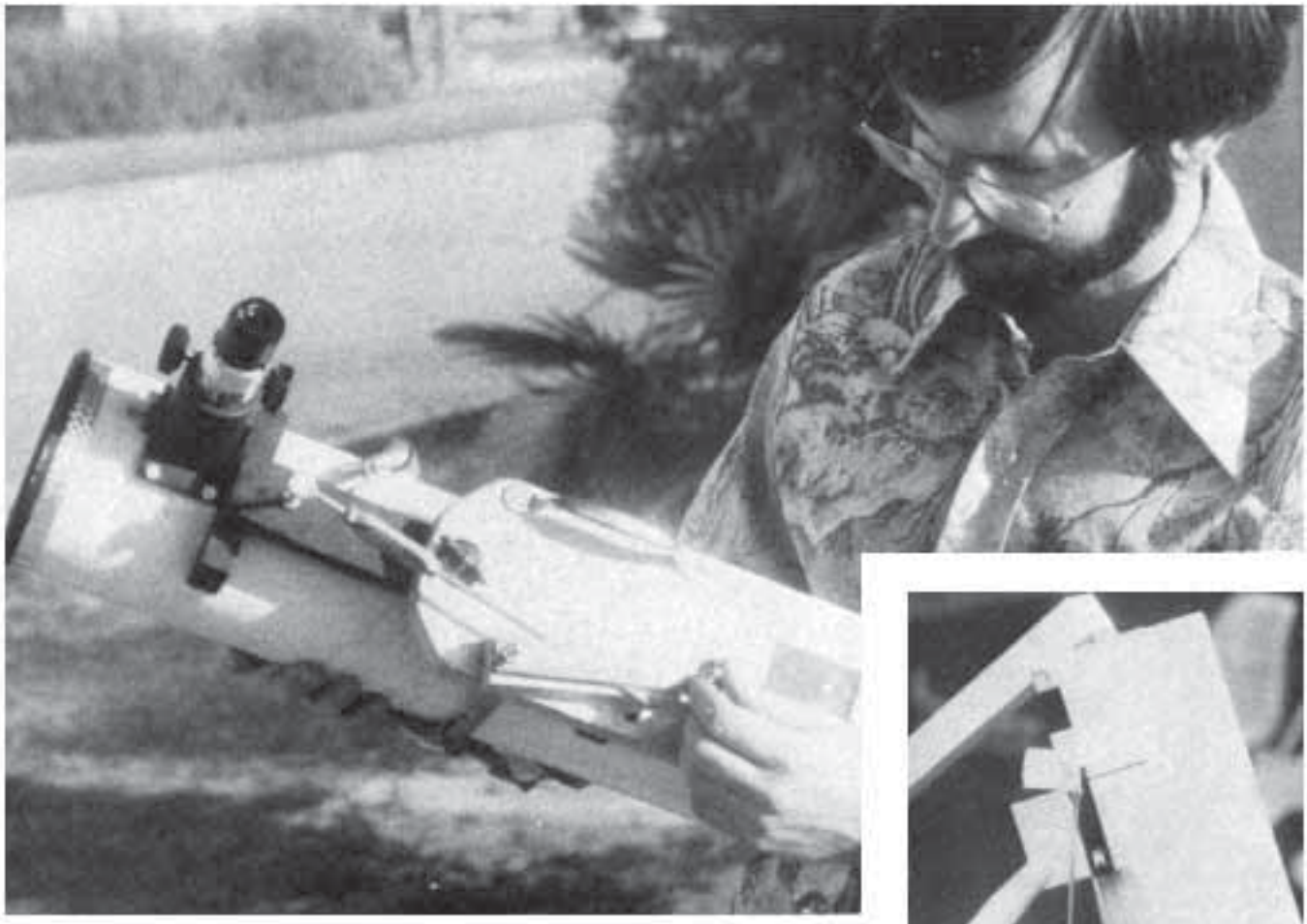
operation. You could use the mount as is, attaching the scope to the cradle, but a set of (optional) right ascension slow motions will be very helpful in tracking.

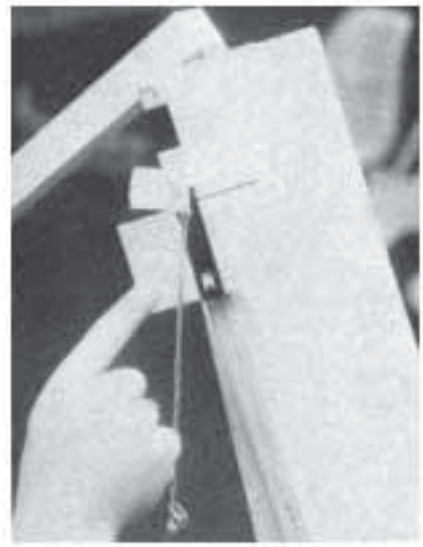
The plan for the slow motions is very similar to that of the declination slow motion. Instead of the bolt through the cradle, two 10-32 × 2" bolts pass through the bottom of each corner of the fork base. They must be countersunk to avoid scraping the easel. Two bolts, one on each side, make it much easier to sweep the whole sky. Also I recommend using two pivot arms, on either side of the top of the easel.

Assembly of these two arms is the same as it was for the declination control. With the wing nuts loose, the arm pivots for rapid east-west motion; with nuts tightened, the turnbuckle allows for diurnal motion tracking up to 20 minutes before being reset.

It's easy to disassemble this mount for transporting in a car trunk or storing in a closet. Remove the large wing nut, then take off the scope tube and fork. Next, unscrew the three wing nuts holding the eyepiece tray so the legs can be folded. The tray itself slips over the ⅜" bolt through an eyepiece hole, and can be attached by screwing the large wing nut







back on. The entire disassembly takes only three minutes.

This telescope has been used by several youngsters. They've encountered few problems in either finding or tracking the Moon and planets. While the f/4 optical system is not made for high powers, the ⅛ wave accuracy and use of a 3" aperture reducing mask does provide fine views at 60x. Optically and mechanically, it would be hard to duplicate the performance of this scope for only $70.

I suggest you add the following, listed in order of importance, if you want a fancier unit: 1.) a 5x24 finder (about $14); 2.) a rack and pinion focuser ($20); and 3.) photo adapters ($15).

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■

the cheap, no legs, stable,

"From the smallest to the largest mirror, don't deprive yourself of the fun of making them all!" Well, that's what they say, but the same cannot be said of mountings.

With mountings it's important to do things right. "Shun the smallest and use the largest" when it comes to bearings and shafts. Use the largest you can find. This applies not only to fancy machined mountings, but to the very simplest designs such as the classic telescope-on-a-beam.

The base shown in the accompanying photograph uses concrete, cast in a plastic bucket, for weight and stability. At the bottom of the bucket (which is the top of the mount's base), a long central bolt passes through a metal plate 6" in diameter. The bolt extends out the bottom of the container and serves as the azimuth axle. (The bolt must be at least ½" diameter. Its protruding length is determined by the thickness of the beam carrying the counterweight and altitude bearing.)

To hold the plate in the concrete, three long bolts extend from it into the bucket. As further reinforcing, some coat hangers bent in random fashion are placed in the bucket interior.

After getting it ready, the bucket is filled with concrete mixed dry for strength. After pouring, keep it damp with wet rags and in a cool location until the material has set. When the concrete is dry, cut the bucket from the unit and glue three hard rubber heels to the base. This base has no legs (to trip over in the dark) and is easy (and won't get in the way) when the telescope is stored or transported.

The ball bearing for the azimuth is homemade. It uses six ⅜" steel balls held in place by a retainer, slightly thinner than the balls, which locates them close to the edge of the 6" plate on the base. (The holes holding the balls are ⅜" clearance holes equally spaced in the retainer plate.)

The top surface of the bearing was hacksawed from a scrap of 3/16" aluminum square sheet cut from a larger plate. At the center of the plate, I drilled a clearance hole for the azimuth bolt. In preparation for making the cast-concrete altitude arm, I also drilled holes for several long bolts to extend through the plate and into the arm.

Make up a wooden form for this horizontal beam, offsetting the vertical shaft about 1/3 the total length to optimize the counterweighting. Fit the metal plate in the bottom of the box and protect the vertical shaft with loose-fitting plastic tubing while pouring the concrete. Be sure to put some reinforcing metal pieces (more coat-hangers will be fine) into the concrete for strength.

For the altitude bearing, I used a ½" lawn mower wheel ball bearing on the small end while the end near the telescope was a homemade bearing similar to the one on the vertical bearing, but with a 3" surface.

It is truly amazing how much weight these bearings can move with so little torque and if their action is too smooth, it may be necessary to add a small brake of leather to make control easier.

This mount was made in 1958. Today, instead of ball bearings, I would use a teflon pad between the two metal surfaces, or teflon squares running against formica, to make the bearings.

The optics are mounted on the simplest type of support. It allows me to try out different size mirrors with a minimum of effort. The primary mirror is mounted with some ¾" plywood on a piece of redwood 2" x 4" and some 80" long — the 8-inch mirror being an f/10 design.

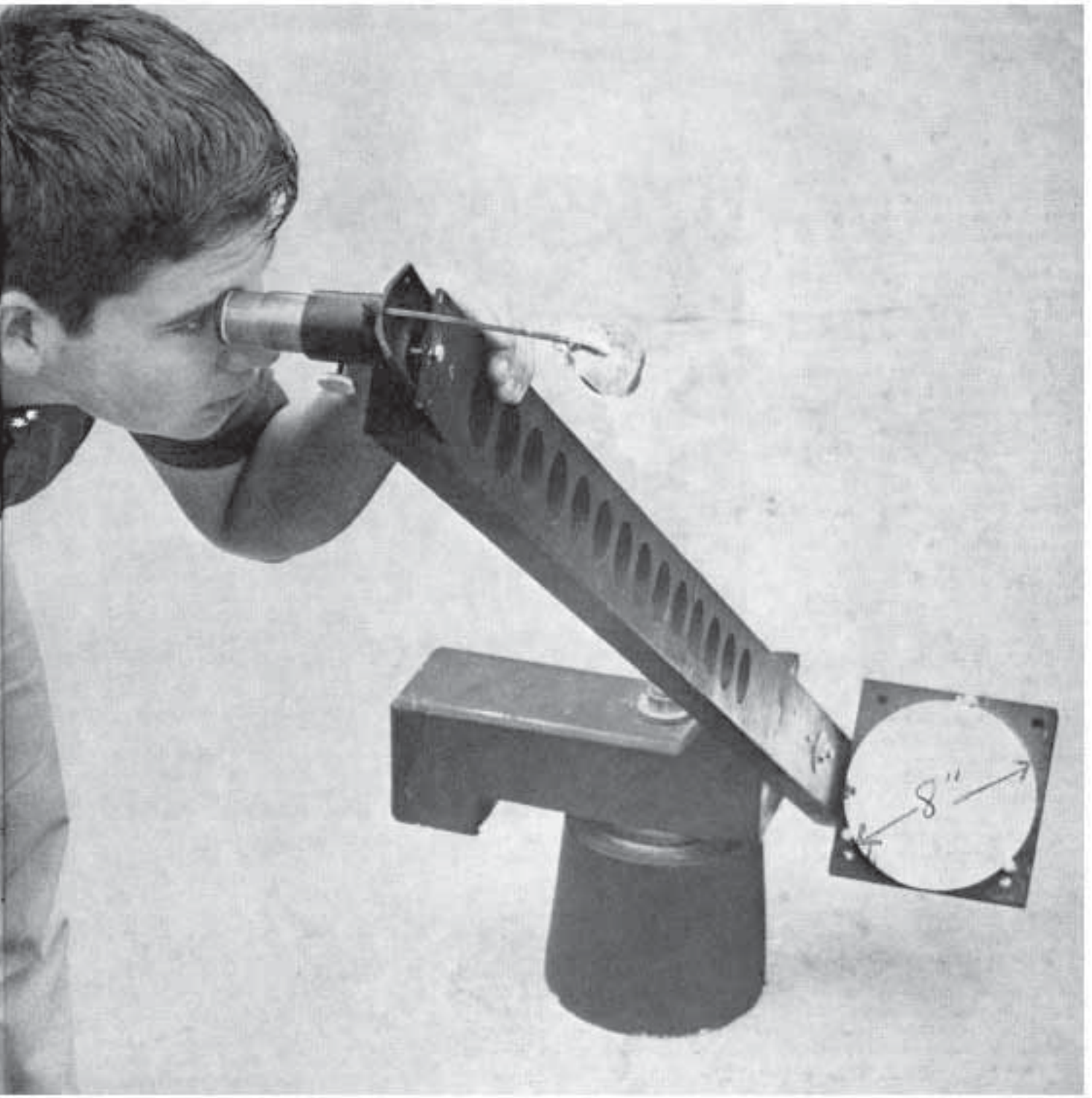
The many holes in the long support allow me to easily move the diagonal and eyepiece when using other mirrors — just stick your diagonal and eyepiece through an appropriate hole, align the optics, and you're ready to test the mirror. It may be necessary to balance things up a bit.

You should look around for parts for the pier with an open mind. There are some excellent rectangular plastic containers for those who want a higher type pier and don't want to use a sonotube.

Richard A. Ely
6175 West 14 Lane
Hialeah, FL 33012

■

portable telescope mount



try a tiny RFT

The trend in these years of spiraling mirror blank prices and decreased prices for good commercial optics has resulted in fewer people discovering the outright fun of pushing glass. The design presented here, besides being a top performer, can act as an easy, inexpensive "make-your-own-optics sampler" for the novice amateur telescope maker. These instruments, small RFTs, are perfect as beginner scopes or as auxiliary instruments.

The optical system is basic and classic. A 3" or 3.1" rich field primary (f/4-f/5) with a 1.3" diagonal mirror. Edmund Scientific used to be a source for 3" mirror blanks, but they have now dropped them from their catalog. However, 3.1" Pyrex blanks are still available from American Science Center, 5700 Northwest Highway, Chicago, IL 60646 (part #8180).

Most of the remaining parts are familiar off-the-shelf items:

From Edmund or ASC

- #80,056 3-9/16" i.d. spiral paper tube (makes 2)
- #50,109 3" mirror cell
- #61,057 diagonal holder
- #60,049 diagonal holder

From Various Sources

- 2" focusing mount (low profile preferred)

or:

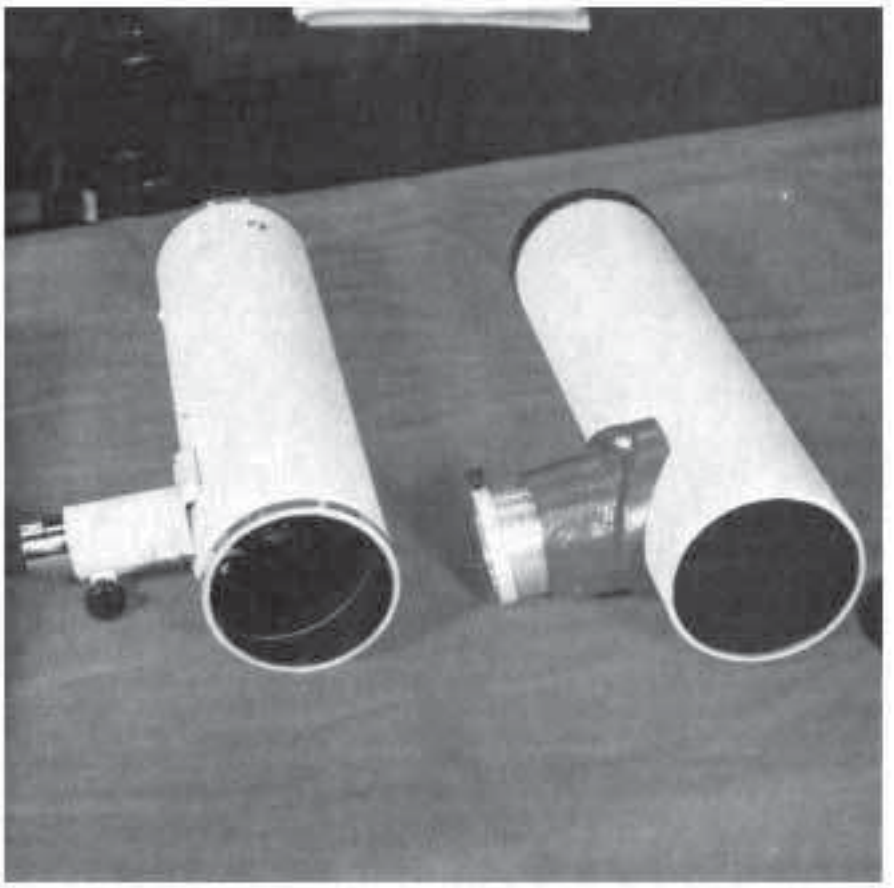
- 1¼" focusing mount (cheaper, but restricts performance)

and

custom-made

- support block for diagonal holder or special holder (needed for 2" focuser only).

Most people react with surprise at using a 2" focuser on a 3" scope, but the design truly requires one for maximum performance. However, the tall profile of most available 2" focusers makes for a cumbersome instrument and an oversize secondary mirror. With the scratch-built focuser shown, I hope to strike a happy medium.



These telescopes will give their best deep-sky performance when used with 25-32 mm Erfle-type eyepieces. The old military 32 mm Erfles, sold for many years by suppliers, are a perfect match, particularly if first stripped of their diopter focusing sleeves. Alternately, if the scope is going to be used strictly as a finder, you could omit the focuser entirely and mount a focusing eyepiece on it instead.

Cradled in your arms, one of these little units more than equals a pair of large binoculars for sweeping the southern Milky Way. Because of the angle of the eyepiece, there is less neck and arm strain. Used as a finder for a large Newtonian, you get the advantage of the same field orientation as in the main instrument. All in all, this somewhat overlooked design is economical, flexible, and fun to build.

John Allseits
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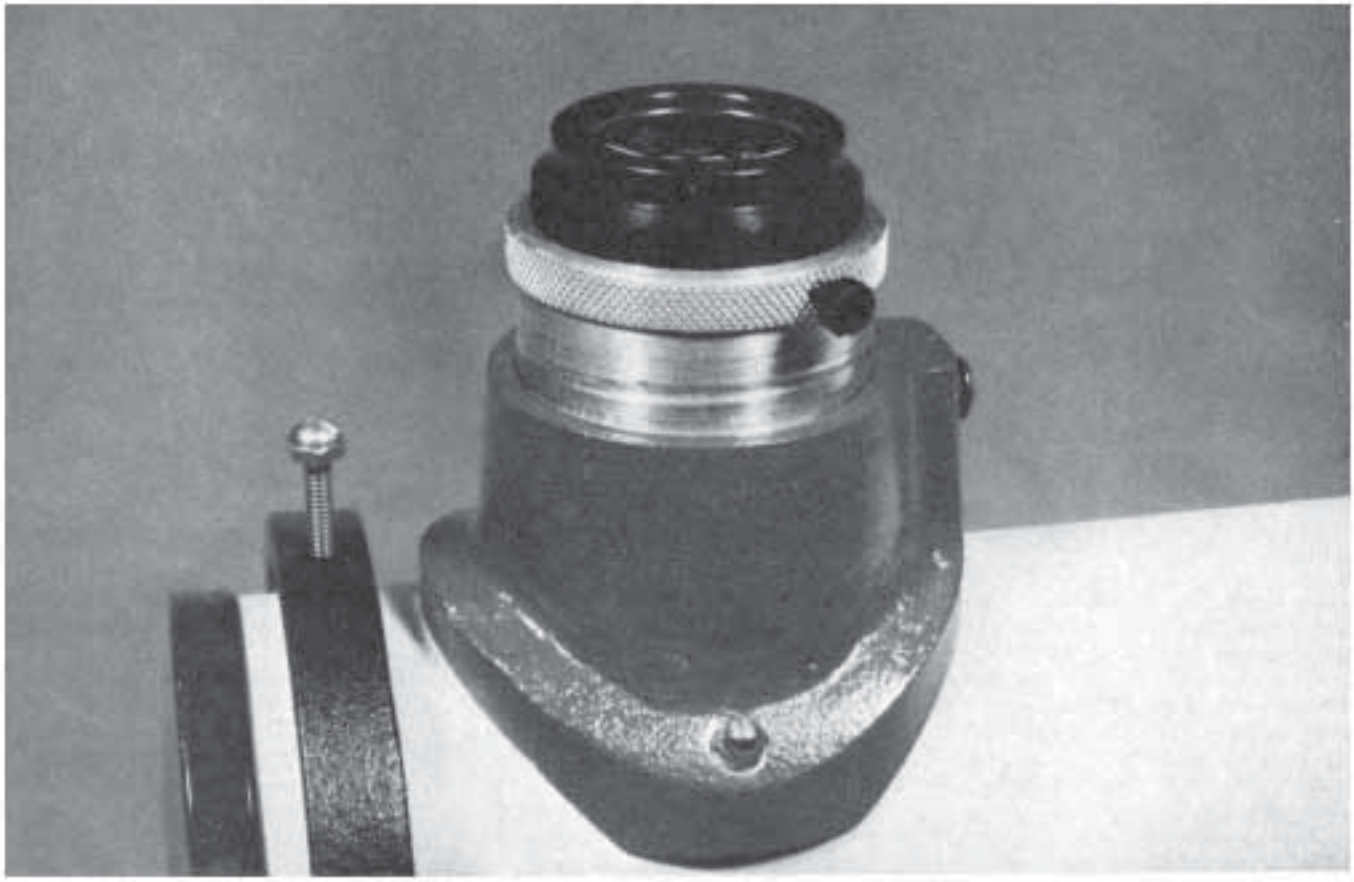
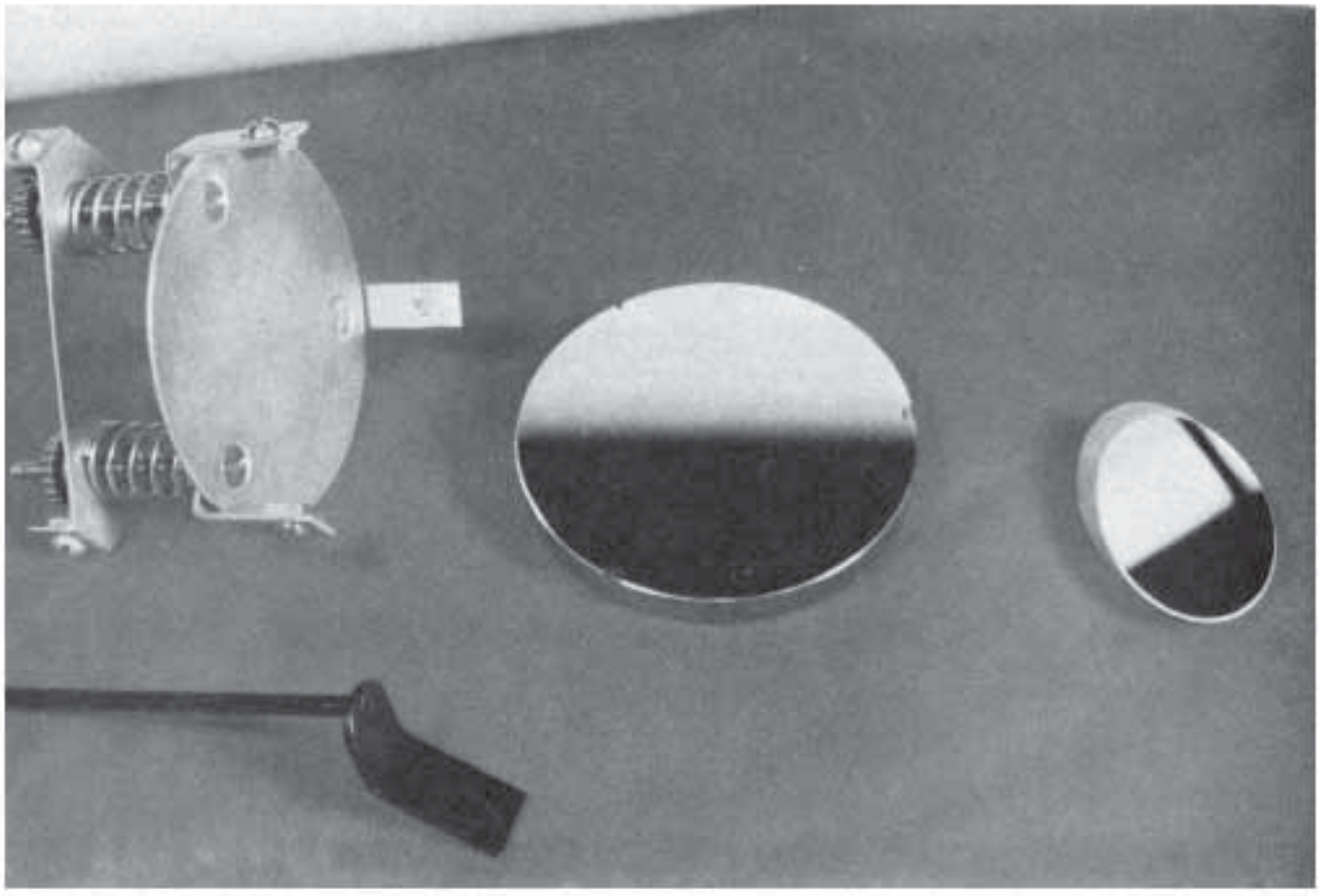




Stalking the Wild Paraboloid

Let's say you've polished a mirror. You've put in long hours of tedious labor grinding and smoothing the curve just right and spent even longer hours bringing the glass surface to a high polish. After the crucial few minutes of painstaking — perhaps terrifying — parabolizing, it looks good under the knife-edge.

But is it *really* good or is more work in order? After all, telescope making writers often contradict each other on the difficulties of figuring. Texereau, in his book *How to Make a Telescope*, promises with optimism, "A polished mirror is nearly a finished mirror," while *Amateur Telescope Making — Book One* quotes one dismal optician as saying that a polished mirror is only one-fourth done! Other opinions fall between these extremes. Whom can you believe?

Well, fortunately, you don't have to believe anyone. Although the Foucault test is notoriously hard to interpret, alternately too sensitive for insignificant defects such as central holes and hills and not sensitive enough for disastrous flaws such as turned edge and astigmatism, the mirror maker who follows the graphical method detailed here can evaluate his optics with certainty and rest assured that he knows whether or not his mirror will perform to his expectations. A single calculation will suffice for the entire figuring process.

The key to this method (first presented in the February 1976 issue of *Sky and Telescope* by Adrien Millies-Lacroix) is a simple calculation of the exact tolerances allowable on a glass surface. A graphical plot of these tolerances shows how far you may let your curve deviate before such errors will degrade the final image.

Many writers in the past, notably Franklin Wright and Sam Brown, have offered vague instructions in the form of percentages, such as an allowable 44% over-or-under correction for a 6-inch f/8 mirror. This is a misleading approach. It tempts you to conclude that the center of the mirror is its most critical zone.

Actually, most telescopes don't use the center zone at all since it is obscured by a secondary element. Most of a mirror's surface lies in or near the edge zone; thus it is this portion which must be figured as painstakingly as possible for the very finest performance. I will return to the reasons for this later.

Mirror Math

At this point a somewhat sobering thought must be introduced: There is no such thing as a perfect paraboloidal mirror! William Herschel never made one, nor did George Ritchey, nor have any of the excellent optical firms who produce the world's highest quality telescopes. The perfect paraboloid is an unattainable ideal, a vanishing case of zero probability lost between an infinity family of ellipsoids on one side and hyperboloids on the other. We may speak of our mirrors as paraboloids for they perform like them, but they are not; at best they are extremely prolate ellipsoids or mild hyperboloids. The odds are stacked a trillion to one against having a perfect paraboloid.

Calculation of Tolerances (Example, 8" f/8.25)

r	r^2/R	$2R\rho/r$	Upper	Lower
10mm	.030	3.75	3.78	-3.72
20	.119	1.88	2.00	-1.76
30	.268	1.25	1.52	-0.98
40	.477	0.94	1.42	-0.46
50	.746	0.75	1.50	0.00
60	1.074	0.63	1.70	0.44
70	1.461	0.54	2.00	0.92
80	1.909	0.47	2.46	1.44
90	2.416	0.42	2.84	2.00
100	2.982	0.38	3.36	2.60

In the third column, the quantity ρ is the diameter of the diffraction spot given by the equation $\rho = 1.22 \lambda F/D$.

We use the Foucault test to measure two basic kinds of surface errors — those of form, such as turned edge or ring depressions, and errors of figure (undercorrection or overcorrection). The first class is restricted to particular zones of the mirror while the second assumes perfect geometry and examines the extent to which the surface deviates as a whole. Analytic geometry classifies the conic section curves (circles, ellipses, parabolas, and hyperbolas) by their "eccentricity" or the constant ratio maintained between each focus and a straight line called the directix for each point on the curve.

In the optical shop, however, we use a more practical expression, the coefficient of deformation (which is the square of the geometrical eccentricity), that lends itself to a linear measurement of spherical aberration at the center of curvature. Thus if the knife-edge is placed halfway between the center and edge radii, we see the shadow crest at the 70.7% zone with half the mirror's area on each side of the crest. If we were to use the eccentricity, measurements near the edge would crowd together and hamper analysis.

The familiar r^2/R expression assumes a coefficient of deformation equal to one and tells us, to a good approximation, the difference in radius between our desired paraboloid and a sphere tangent at the center and edge. For an ellipsoid, we would multiply r^2/R by a factor between zero and one, and for a hyperboloid by a factor greater than one.

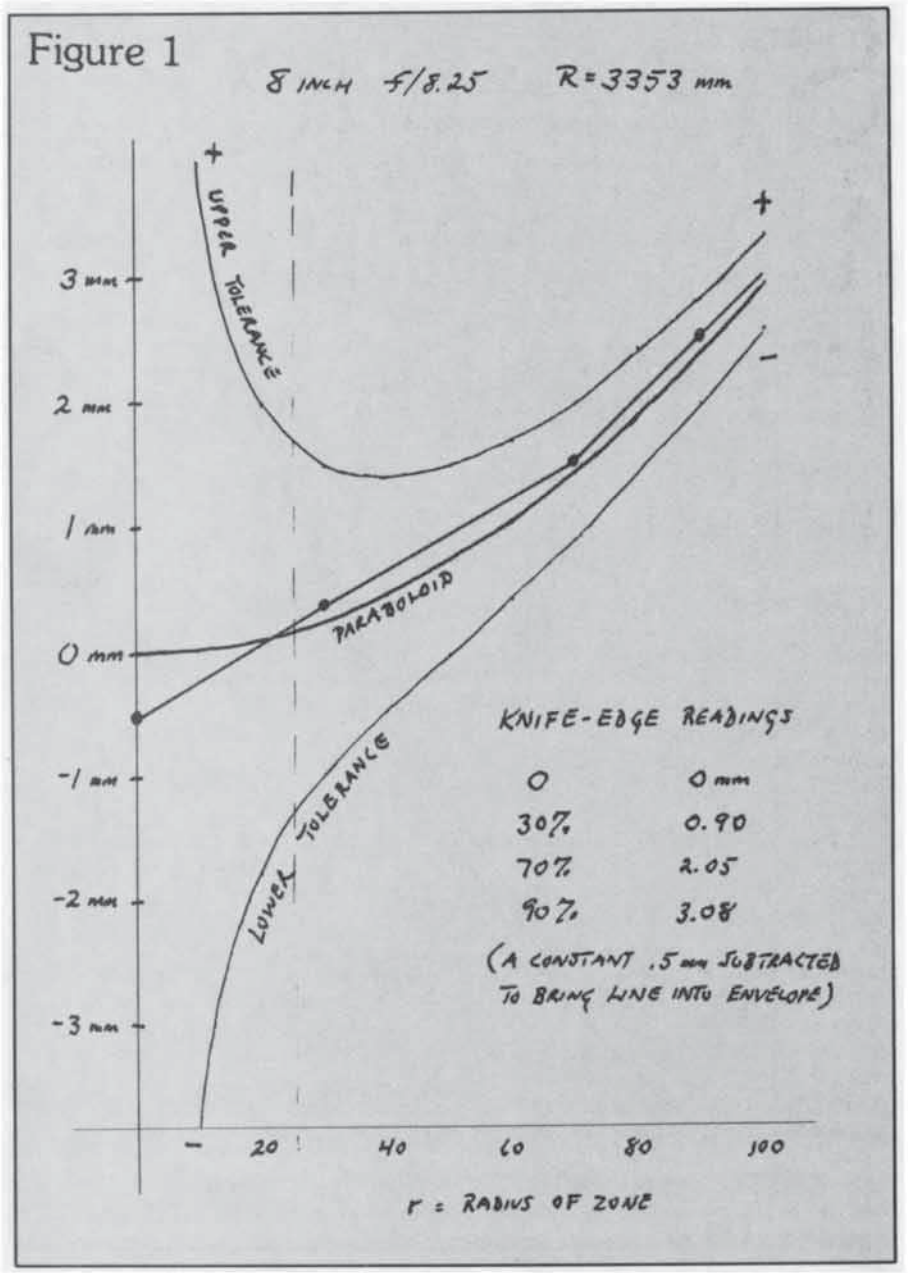
Inverting the relationship, if we measure the spherical aberration and find it is less than r^2/R, then we know our mirror is an ellipsoid, and if the knife-edge shift is greater than r^2/R we have a hyperboloid. The elusive paraboloid is in there — somewhere — but even if we defied all probability and attained it, our measurements are never exact enough to tell us for certain that we have a perfect paraboloid. We must, therefore, content ourselves with a little under or over-correction in any mirror.

As long as the errors in the mirror lie within certain limits, then we need not worry about performance of our less-than-perfect paraboloid. We can thank the nature of light for this, for it is the dimensions of the actual light waves which allow us to tolerate errors in a telescope.

A perfect mirror will reflect parallel light into a spot surrounded by several very faint concentric rings, the well-known diffraction pattern. The size of this spot, B, and ultimately the resolving power of the telescope, is solely dependent on the focal ratio of the mirror as defined by the expression:

$$B = 1.22\ [\lambda] \times F/D,$$

Figure 1



where [λ] is the wavelength of light and F/D is the mirror's focal ratio.

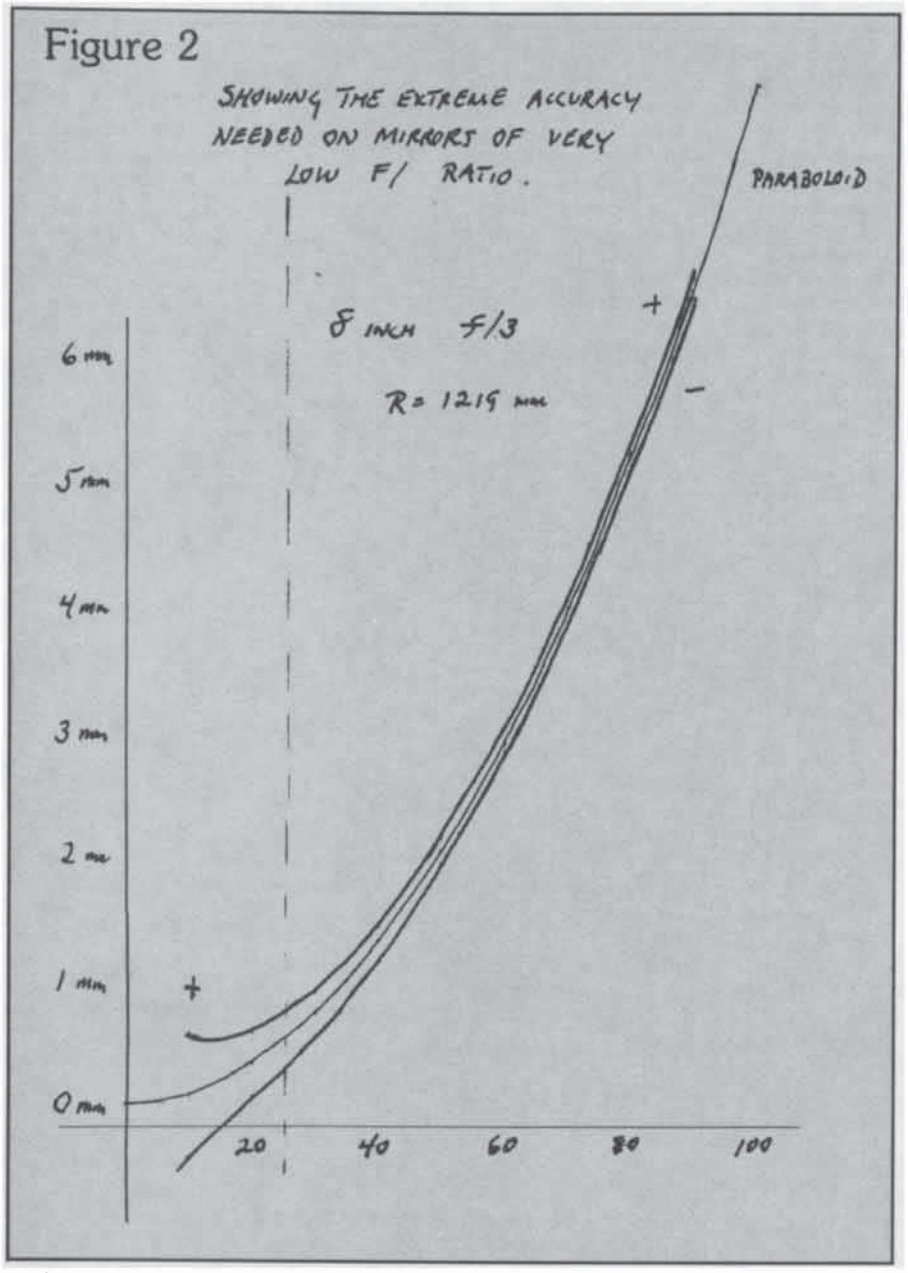
How imperfect can a perfect mirror be? Only so imperfect that the size of the diffraction spot remains the same as the above quality. "Diffraction Limited" is a term you see very often in advertisements for telescopes, and it refers to this degree of accuracy.

Accuracy Where It Counts

In order to illustrate the required surface accuracy for a given mirror, the accompanying table gives a plotting analysis for an 8-inch f/8.25 paraboloid using the values of r and R unique to that mirror. Column 1 is simply the radius of each zone measured on the mirror. The knife-edge shift of a perfect paraboloid is in column 2. The calculated allowable error, or tolerance applicable to column 2 by the zone, is shown in column 3. It is the radius deviation necessary to make a ray just miss the central Airy disk, and it determines columns 4 and 5 as the upper and lower limit of tolerance. I used millimeters because they are convenient in plotting on graph paper (being in tens units) but inches are fine — just don't mix the systems!

Having provided yourself with such a table, the next step is to plot it in graph form. In fig. 1, the vertical scale represents knife-edge travel and the horizontal scale represents zonal radius. The central smooth curve is the desired parabola, plotted from column 2, and the outer curves form a "tolerance envelope" around it.

Stated very simply, if we make a set of knife-edge readings, and they all fit within the tolerance envelope, we have made an acceptable mirror. ➤



Let's consider what the graph tells us. We can see at a glance that the tolerance is rather narrow at the edge and widens gradually toward the center. In fact, near the center practically anything goes, and many a mirror has been ruined by a worker who labors unnecessarily to plane off a central hill and loses a nice edge zone in the process. A central hill looks "ugly as sin" under the knife-edge, but in most instances won't seriously affect a telescope's performance.

A bad edge, however, is intolerable. A radius defect at the very center throws light into the center of the diffraction spot no matter how severe, but a turned edge reflects light outside the spot.

Assuming a diagonal 25% the diameter of the primary, most central errors are hidden behind the obstruction and so don't come into play anyhow. The dashed vertical line in the accompanying graphs represents a central obstruction. The slight hole lies completely under the diagonal shadow. Thus a central error is an "invisible defect", but an edge error will seriously degrade the image.

What else does the graph tell us? In a moderate focal ratio mirror (f/7 and above), we have a wide choice of curves which will fit the tolerance limits. If the readings for the edge and 70% zone are decent, the mirror must be grossly in error if the rest of the readings don't fall in right. We ought, in general, to orient ourselves toward producing a good edge right from the outset by polishing with the mirror below (which gives a better polish anyway) and avoiding soft pitch.

The safest way to use this analysis method is to plot your basic curves and run off a few copies, one for each retouching operation. Then you can plot the knife-edge readings lightly on the graph, move them up and down by a constant amount so they best fit the envelope, and then join them by straight lines. Only a glance is necessary to determine the corrective measure required. If you use a fresh sheet after each retouching step, the plot forms a useful record and can materially assist you in figuring future mirrors, since a particular worker tends to produce the same errors during the polishing operation.

One interesting and instructive lesson you can learn from this method is an estimation of the figuring difficulties of a given mirror without ever touching a piece of glass. If you're contemplating the construction of a Cassegrainian with an f/3 primary, first plot the surface tolerances (figure 2) and then decide if you're a match to the job! (This is a relatively painless way of discovering that short focus mirrors are not for a beginner.)

On the other hand, if you wish to have the easiest possible figuring job, and decide to leave a mirror spherical, the tolerance plot will reveal if such a project is practical. The plot of an f/12 mirror of 8-inch aperture (figure 3) shows that a horizontal line — representing a spherical surface — fits nicely into the envelope.

An Example

The mirror analysis in fig. 1 is an actual mirror made by me and is the second mirror made by this method. It has proved so useful and convenient that I would not make an aspheric surface without it. Before Millies-Lacroix published his analysis, the only way of making an analysis was to go through Texereau's detailed mathematical analysis, not an easy task at the end of a late-night figuring session.

Nor was it practical as a quick check between retouching steps! Usually you had to judge qualitatively — based on past experience — just where to remove glass in order to improve the surface form, and since a typical plot can be juggled about somewhat to render retouching easier, such judging is never reliable. For example, if a mirror has a low 70% zone but a high 50% one, by suitably locating the curve within the envelope (positions 1 and 2), you'll realize that you can treat the 50% zone by blending the surface, whereas trying to raise the 70% zone would prove most frustrating. Figure 4 illustrates this example. You can imagine many more.

The mirror plotted in fig. 1 is something of a lucky case. The surface figure is very close to the ideal, probably not deviating from the paraboloid by more than 1/20 wavelength, perhaps

much less. For a wavelength of light of 5080 Angstroms, 1/20 wavelength is a millionth of an inch — 0.000001"! Without the visible tolerance curve before me, I would have fretted about the hole in the center, mutilated the polishing lap to correct it, and possibly seriously degraded a nearly perfect figure. Such things have happened in the past.

The Millies-Lacroix approach is a tremendous time and labor saver, not only in its accuracy of showing you what you have done, but in its truthfulness in showing what you probably can't do. I have attempted to make mirrors (such as the fast one in figure 2) without knowing the extreme difficulties involved.

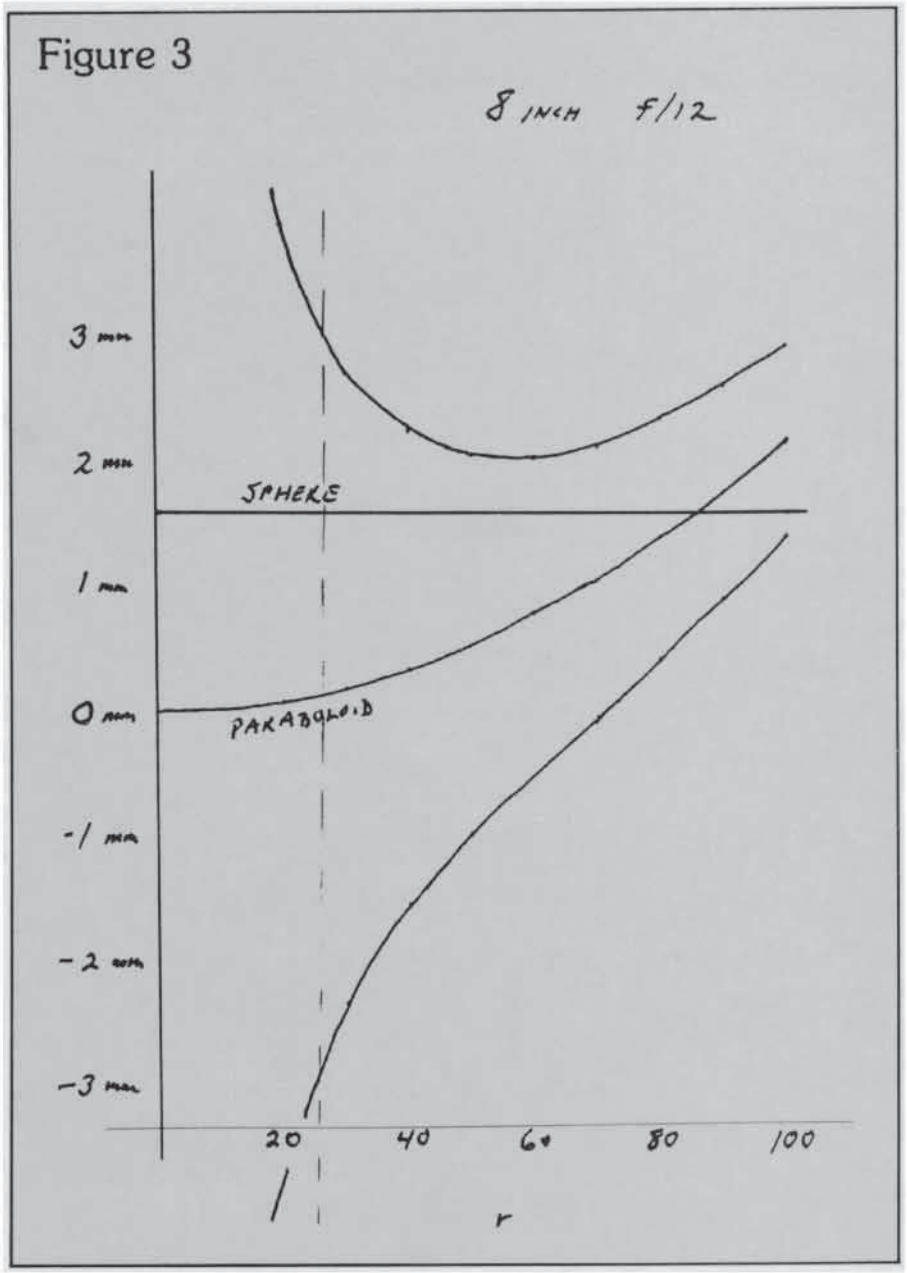
The first plot I made for the mirror shown in figure 1 showed a central hill and low zones at 50% and 70% with the edge a trifle high — a bit undercorrected but everything fit the tolerance plot. However, I decided to further retouch the surface and a single turn around the mirror with a two inch lap not only removed the hill but left a slight depression as well. A very little retouching with the full lap deepened the curve a bit to the figure shown in the drawing.

This is how I might have done the job without the Millies-Lacroix graph: With the polisher on top and mincing ¼ strokes, a spell of one to two hours would produce a high center and edge — an oblate spheroid. In an attempt to parabolize it, the mirror on top, 30 minutes of long strokes would have been applied; then probably finding the center still raised, the stroke would be changed to chordal strokes for four rotations to force down the center, unfortunately probably turning the edge. Abandoning the full size tool, I might have next tried a small polisher to scour the edge, thus wearing a deep groove about an inch inside the rim. Disgusted by the results, I'd return to a full size tool for at least two hours hoping to remove the damage done by the small tool, and when a sphere was obtained, I'd start the parabolizing process all over again. All this for a defect which would have never been visible at the focus!

Working from the Edge

As previously mentioned, the edge is the critical zone of your mirror. Many writers recommend taking the knife-edge readings starting at the center. The reason for this is twofold — you can't see your previous marks in noting the zones (rendering the readings more "impersonal"), and since the base spheroid for the aspheric is the apex or center of the mirror, the center is a logical point to start.

But when measuring in this manner you are judging the entire mirror, in effect, by its least critical zone. A deep center gives the illusion of a seriously overcorrected mirror, and a high center the opposite. The most crucial measurement, the distance between the 70% and 90% zones, is easiest to work starting from 90% and working inward, then plotting the average of at least four sets of measurements. In this manner, you can be certain about matters of over and under-corrected figures. Done carefully (and intelligently) the edge zones are far stabler than the center, and as long as they're not turned, they provide a more reliable bench mark for testing.

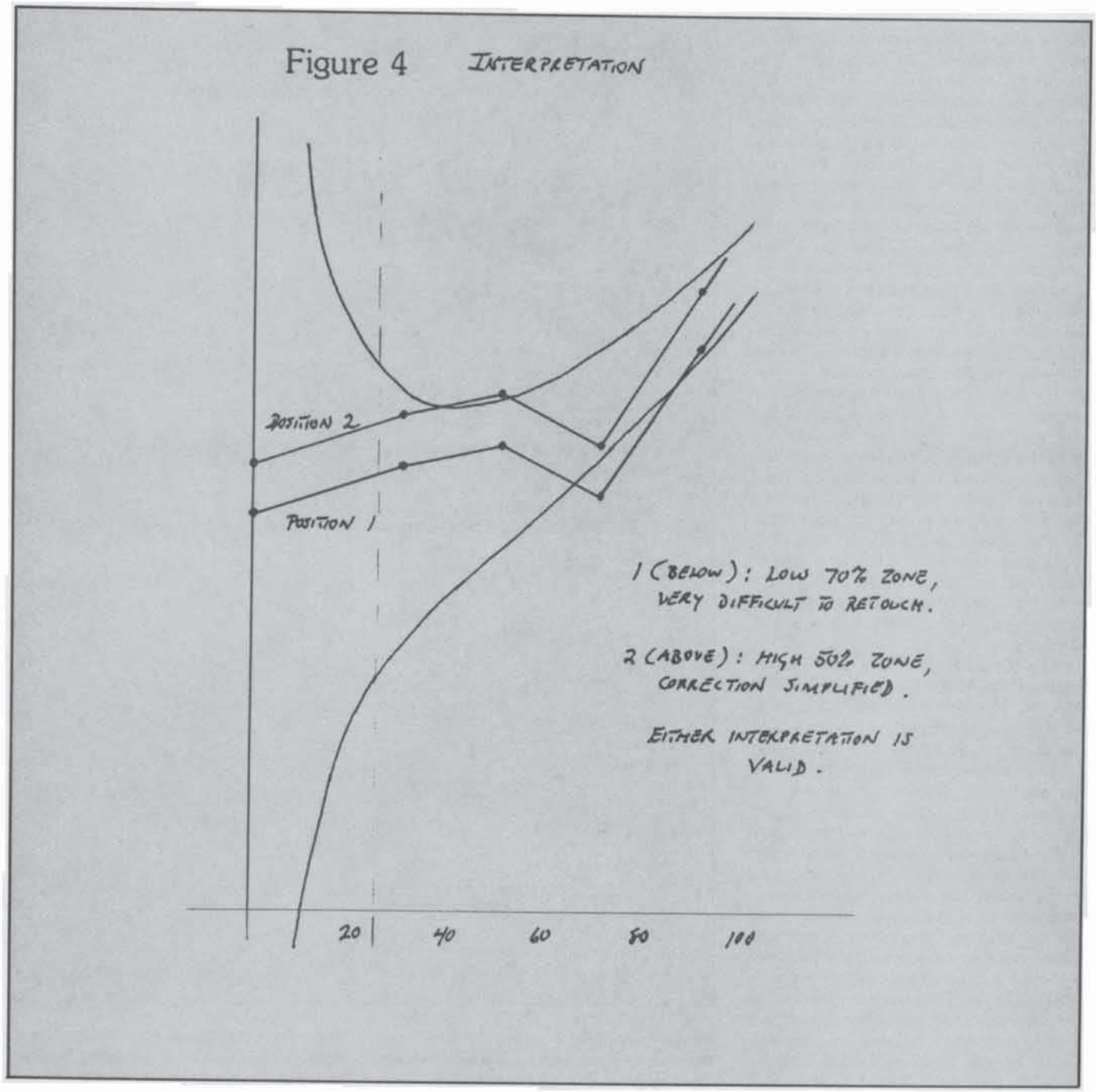


Mirror Performance

A few general inferences should be drawn from the tolerance curves. From *A.T.M.*, you could get the distinct impression that the very worst flaw a mirror can be afflicted with — worse than zonal defects, surface ripple, astigmatism, or what have you — is abrasive pits. This is, of course, false. Probably every mirror in the world has a few pits since no polish is perfect. Some amateur mirrors may have thousands, in fact, and work well anyway.

As for astigmatism, it is highly unlikely that a mirror worked by any reasonable method, and probably a variety of unreasonable ones, will develop a perceptible degree of astigmatism. This defect is more likely to be caused by improper mounting of the optics than by the optical work.

It is zonal defects, especially zonal defects near the edge, which are the overwhelming cause of mirror failure. Multitudinous sleeks on your mirror will not scatter as much light as a turned edge a tenth of an inch wide. ➤



Success in optical work depends on maintaining a healthy perspective — and the Millies-Lacroix diagram is the truest perspective of a mirror surface at your disposal. It won't hide your mistakes, but it will tell you which ones are serious enough to attend to and which can be ignored. Above all, in combination with brief notes about corrective measures employed, it freezes your experience in a form which is easily recalled and provides an incomparable learning method.

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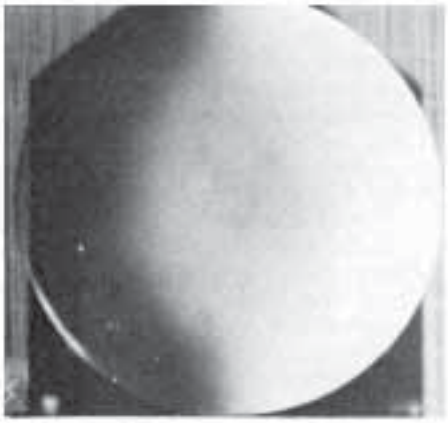
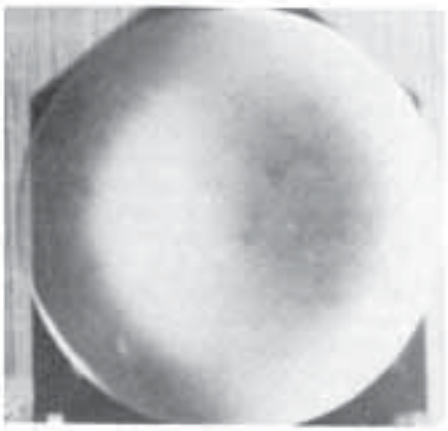
Bob Cox adds:

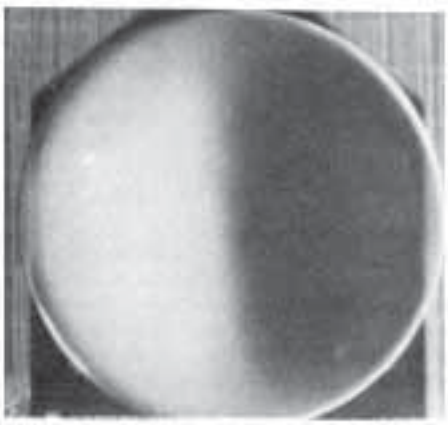
In introducing the graph in fig. 1 and its indicated results, Mr. Miller stated the mirror was "acceptable". Actually this mirror is just about perfect, but in order not to mislead the reader, a conservative approach was taken. Any series of plots falling within the tolerance envelopes will represent an acceptable mirror, but what then is the difference between acceptable and excellent?

Examining figures 1 and 4, the answer is obvious — smoothness! Of the two mirrors, the one that plots out as a regular and smooth curve (rather than a "sawtooth" plot) will give the superior image. The discriminating observer who is looking for faint low contrast details on the planets and Moon will do better with the smooth curve corrected mirror. A smooth figure is also less adversely affected by temperature, requiring a much more drastic change to throw the mirror out of tolerance. ■

How to Make Focograms







When you're polishing and figuring a new mirror or studying an old mirror that hasn't performed up to your expectations, it's a fine time to be making focograms.

Set up a single-lens reflex 35 mm camera, or one with a ground glass back, between the knife-edge and your eye. Focus the image on the ground glass, set the f-setting wide open, and open the shutter with a cable release at bulb or time for several seconds.

Medium speed pan film like Plus-X with fine-grain development produces a long gray scale with exposures on the underside. Experiment with enlargements on different contrast papers, especially the softer grades, to print the subtle detail that is lost with too much contrast.

Optimum exposure time depends on such factors as light source and width of slit, the focal length of the mirror, focal length and f-stop of the lens, and film speed. Any guess of several seconds exposure is a good start, but bracket widely. The best approach is to shoot a roll and keep a log on all the variables.

My 135 mm lens at f/3.5 is quite satisfactory for negative size and shadow detail with less enlargement, though for long-focus mirrors you may want to use a longer telephoto. The wide open lens setting allows the entire expanding cone of light to enter the lens. Some room light is desirable, but keep it low enough not to show up irrelevant detail back of the shadows.

Experiment with variations in width of slit, Ronchi screens, and make records of your tests with Couder mask settings with the masks removed. If you want to doublecheck yourself, you can confirm the positions of the crests of shadows on the parabolic mirrors from focograms.

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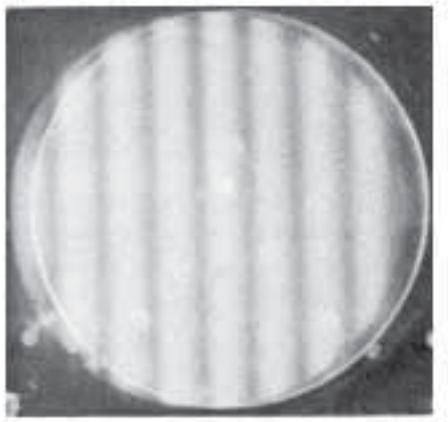
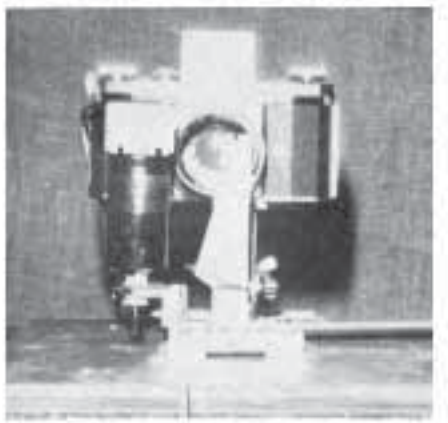
■





Mirror Grinding with a channeled tool

If you're contemplating making a telescope mirror, why not make it easy on yourself and save some time in the process? You can do so by utilizing one of the tricks that professionals in the optical industry have been using for years, namely, a channeled grinding tool.

This type of tool is used by precision opticians because it offers much over the solid surface tool. In grinding with a channeled tool, not only are the problems of trapped air bubbles eliminated, but also the pitfalls of a turned-down mirror edge caused by coarser abrasive grains being pushed to the outer edges of the grinding surface. More importantly, channels prevent the mirror and tool from seizing and locking together during the latter stages of fine grinding, and the all-too-frequent lumping-up of finer abrasives which can cause horrendous scratches on the mirror.

As an added bonus, a channeled tool also reduces the bulk amount of abrasive used per wet and cuts grinding time almost in half. Is it beginning to sound interesting? Well, if you want to take a few extra minutes to make one, these are the materials you need;

Ceramic Tiles:

Although these plain hexagonal white tiles used to be very common in tile stores, I haven't been able to locate any for the past five years. But look around; you might get lucky and find a local source. The only optical company that I know of today that offers them is the Willmann-Bell Co., P.O. Box 4626, Springdale, CT 06907. The latest price is $2.95 ppd. for enough tiles to cover a 12½" tool with a few left over.

Epoxy Glue:

Any clear slow-drying epoxy glue will work. Don't get the type that sets up in 5 minutes or you'll end up with a lot of wasted glue in your cup. Don't bother with any of the so-called "super glues" unless you don't mind tiles popping up loose in the middle of fine grinding.

Backing Plate:

Although built-up disks of ¾" plywood may be utilized, they're not good because no matter what you do to them, they end up warping. Although metal or granite disks may be utilized, procuring and shaping them presents a problem.

Far more practical as a backing plate is either a standard plate glass tool or a homemade cement one. You can make a cement tool by placing a ring of cardboard around the edge of your greased mirror blank, secured with masking tape that extends about one inch above the face of it. A mixture of pure Portland cement and water with no sand or rock added to it is then poured onto the mirror up to the top edge of the paper collar and leveled off with a flat stick. A yardstick works admirably.

Once the cement has set up overnight, keep a wet towel or cloth over it for two or three days until it has finished curing. Then the collar can be stripped off, the tool removed from the mirror, and the edges beveled with a surform shaper. After it is completely dry, epoxy the ceramic tiles onto it.

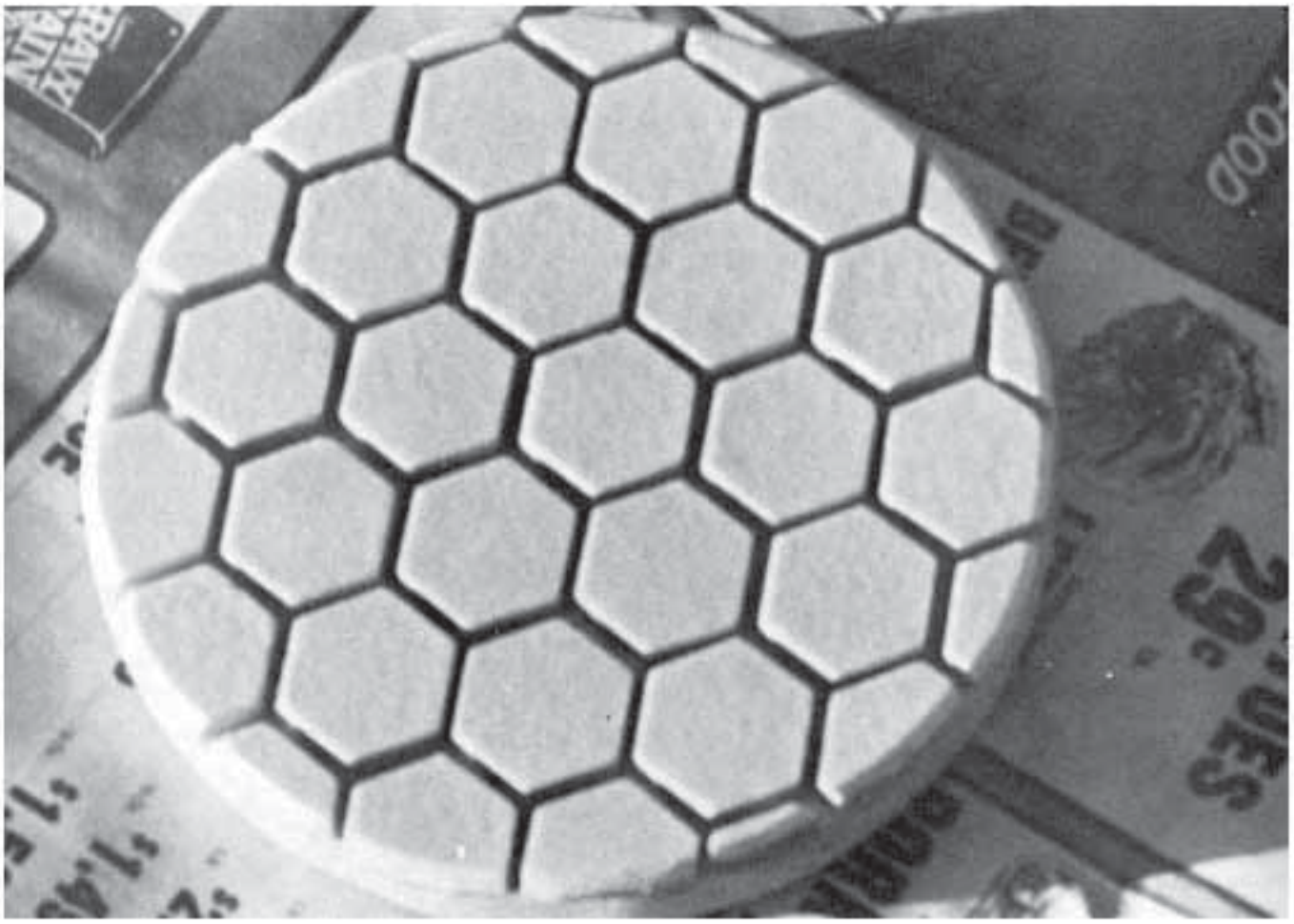
Tile Cutters:

You can either rent these from a tile supplier or you can do what I do — use an old pair of wire cutters. You might also try a hammer and chisel.

Assembly Steps

Place your grinding tool, face up, on a piece of newspaper. In a paper cup, squeeze in both tubes of epoxy glue and mix them together. Next, take a pencil and mark the approximate center of your tool. Begin by spreading some epoxy with a thin stick or a wooden match on the back of a piece of tile. Place this piece down on the tool so that one of the pointed edges covers the marked center point. By not centering this tile you will insure yourself of a zone-free grinding area.

Continue gluing the rest of the tiles



down leaving 1/16" to 1/8" between tiles. As you glue them down on the tool surface, move them around a little bit to squeeze out some of the epoxy glue so that it forms a little bead around the edges of the tile. This will make cleaning of the tool between different abrasives easier later on.

Continue placing the tiles down working toward the edge of the tool. Don't overhang any tiles and don't bother to complete the edges until the whole face of the tool has been covered first. Then the edges can be filled in by marking a tile with a pencil and nipping off, with your cutter, what extends over the edge. The outer edge of the tool does not have to be completely filled in. (If you're lacking less than ¼ of a tile, you needn't bother with it.) After the tool has been assembled and has completely dried, bevel the edge with a grinding stone to insure that none of the tile edges will chip off during grinding.

Grinding Procedure

Now the easy part begins. Take a piece of ¾" to 1" masking tape and run it around the outside of your tool right up to the top edge of the tiles. Overlap it by about two or three inches. This will form a dam that will hold in your abrasives during grinding. Starting with your roughest abrasive, sprinkle on enough to completely fill in all the channels between the tiles. Any excess should be swept off and saved for the next wet. Take a water bottle and spray it onto your tool until the abrasive is thoroughly wet.

Start grinding as you normally would. You will find that — much to your surprise — you won't have to stop every two or three minutes and change the abrasive charge. By simply adding a little more water whenever the grinding action seems to be slowing down and by swirling your mirror around a little bit to raise up some of the abrasives trapped down in between the channels, you can keep right on grinding. As you proceed to the finer grades of abrasives, this uninterrupted grinding period will lengthen. When a charge of abrasive is fully spent, simply wash the tool off in a bucket, recharge it as before, and continue grinding.

Each time you change to a finer abrasive, first discard the masking tape collar and scrub in between the channels with an old tooth brush under running water. Apply a new masking tape collar, charge the lap, and begin grinding again. Once you reach the finer abrasives, #600 and up, simply mix them with water and a drop or two of dish detergent in a clean water bottle and squirt this slurry onto the face of the tool. You need not fill the channels up to the top as before.

With your last fine abrasive, you may find that you only need three charges to complete the wet. Add only clean water to these last charges to lengthen them out so that the smaller broken-down abrasive particles continue to do the work of even the finer abrasive grains. This will help speed up the polishing that follows.

To use your channeled grinding tool for a pitch lap, simply fill in the channels with hot pitch, let it cool, then scrape off the extra pitch left on the face of the tool with a sharp wood chisel. You may then proceed to make a pitch lap as you would do with any other type of solid tool.

Although it may seem to involve a lot of initial work to make this type of tool, the rewards and benefits that can be gained from it, not to mention the grinding time saved, are well worth the extra effort it takes to do it. Once you grind a mirror on this type of tool, I suspect you'll never again settle for anything less. I know I've been spoiled, and I think you will be too.

David A. Aguilar

■

a simple knife-edge tester

What is handier to use for mirror testing than an accurate Foucault tester and a universally adjustable mirror stand? The above two units joined together in a firm but adjustable manner! Well, here it is:

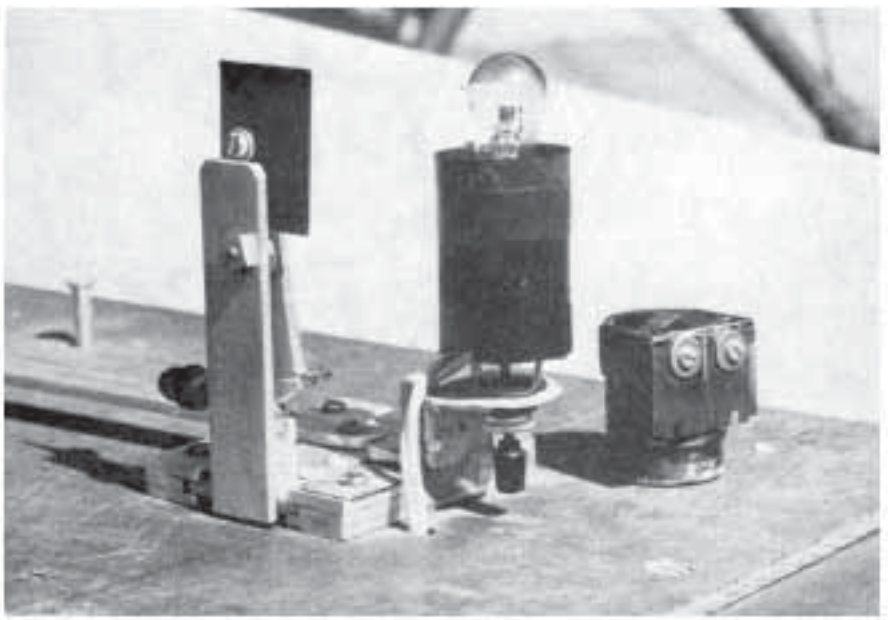
Knife-Edge Tester

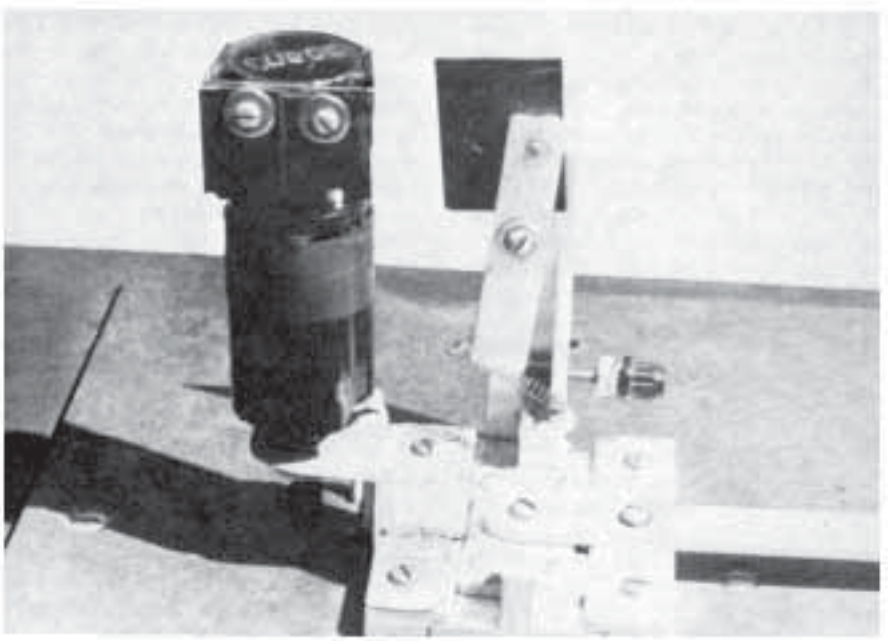
My Foucault tester is another variation of a type originated with Kelvin Masson and described in Neal Howard's *Standard Handbook for Telescope Making* (1959). It has a knife-edge mounted on a slide moved perpendicular to the mirror by a lever arm at a 10:1 ratio, with a transverse motion controlled by a thumbscrew. The material for the parts is ¾ x ¾ x ⅛ extruded aluminum angle, and ½ x ⅛ or ¾ x ⅛ strips sawed from the same.

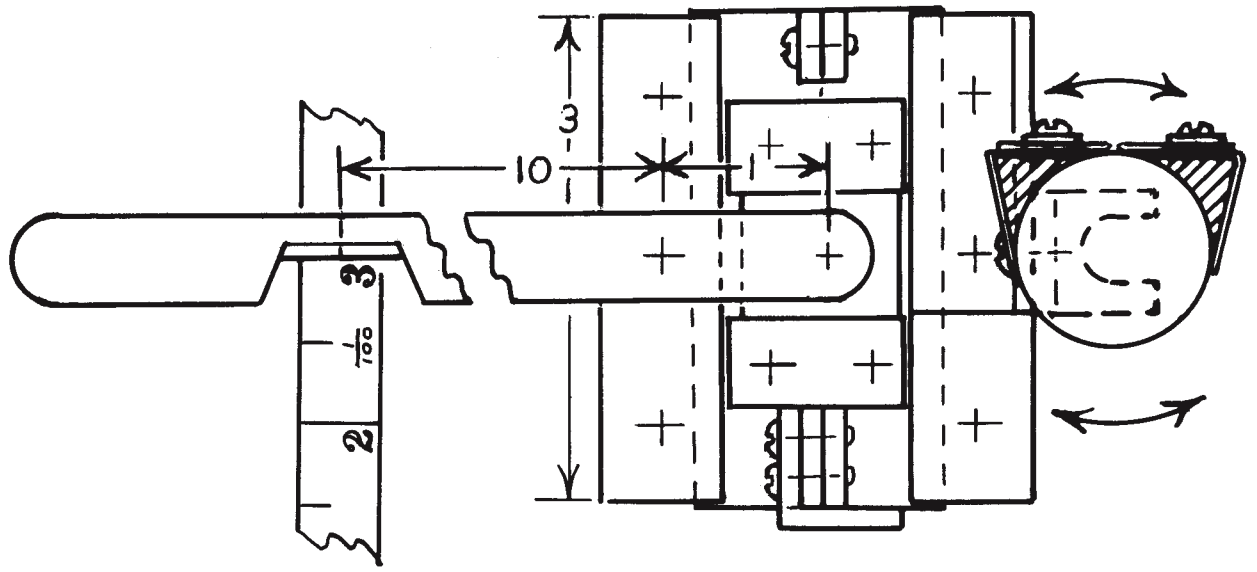
Cut the parts according to the plans, smooth all edges, then clamp parts together securely for proper alignment when drilling holes. Drill all holes the size for tapping the 6-32 thread, then enlarge all the holes not to be threaded with the clearance size, so the screws pass through.

Assemble the slide and stack the glide strips, together with aluminum foil shims in each stack, with the wood screws holding them in shape. Hold the slide between the guides, pressing them together in position on the mounting board, and sink the wood screws. The mounting board is a piece of ¾" plywood, 10" x 20", elevated on two strips of 1 x 2 and supported on three pads.

The cross slide parts and knife-edge stand are fitted and clamped to the slide and screw holes drilled and tapped. Make sure the holes in the lever arm are exactly 1" apart, the end hole threaded 6-32, and the fulcrum hole drilled to permit free turning on the shank of the wood screw with a washer under its head. A tick mark 10" from the fulcrum slides along the scale divided in hundredths.



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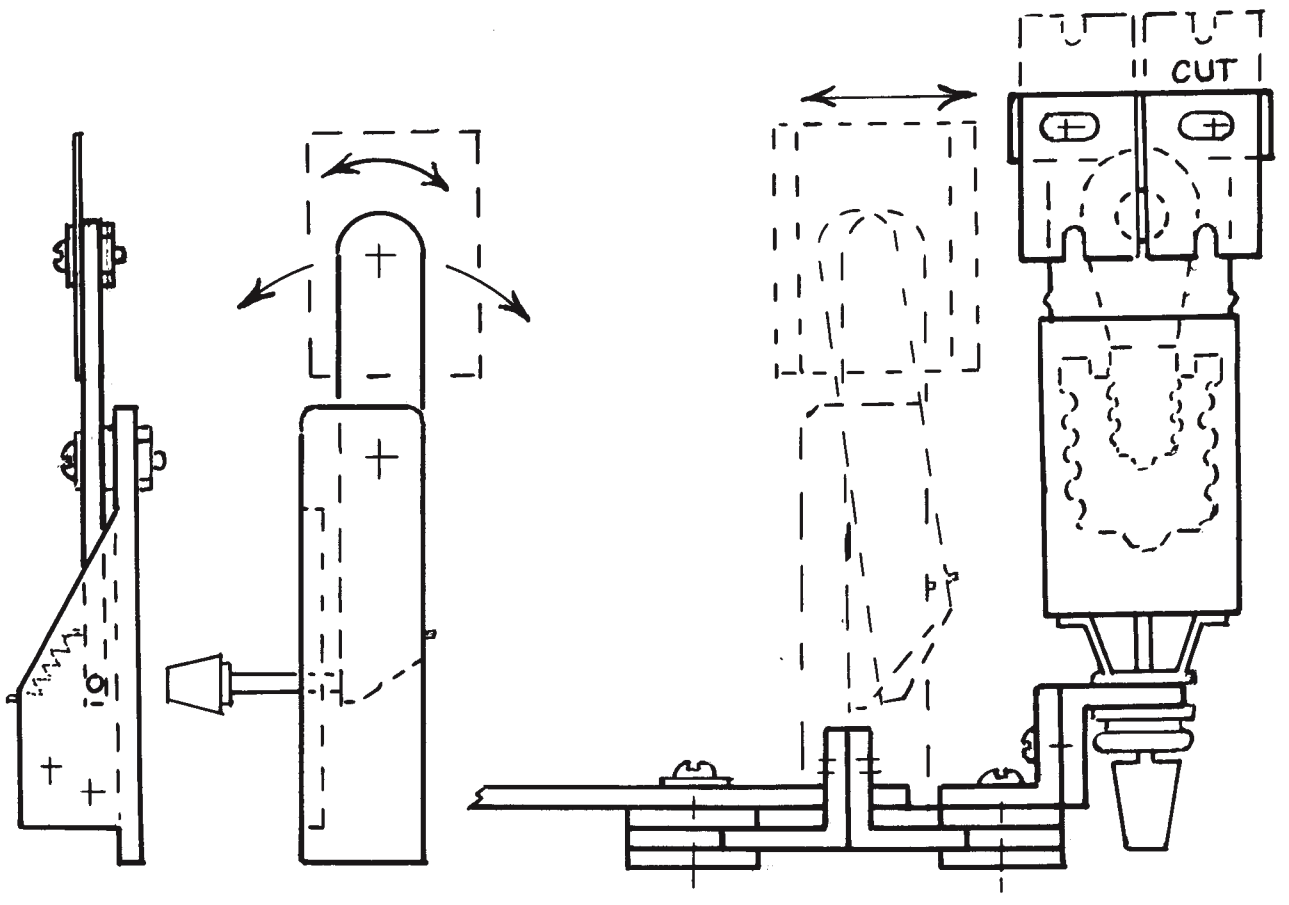
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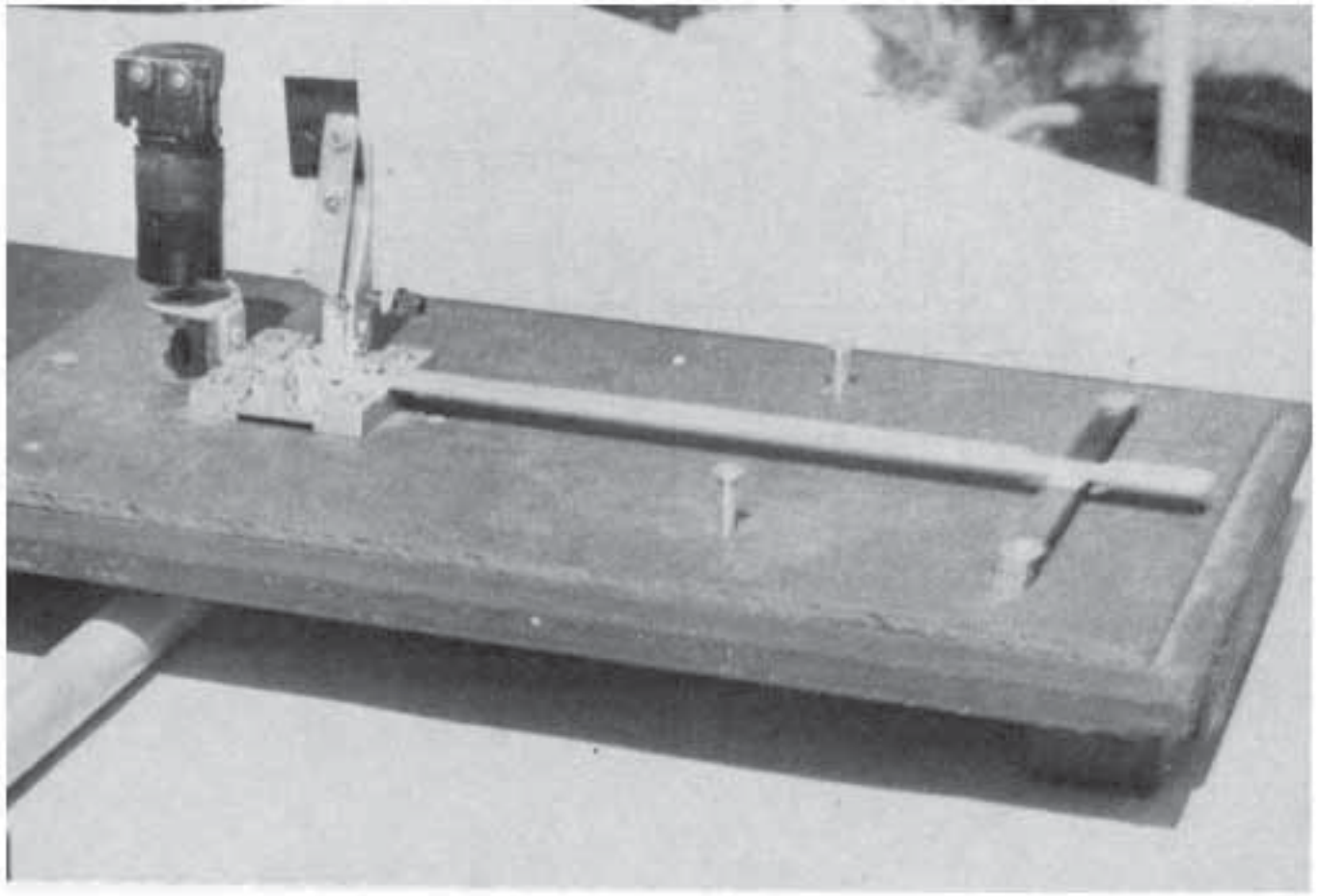


Tighten the screw in the end of the arm so it's secure but turns freely.

You can work in all sliding parts with a bit of fine emery and oil if necessary, but clean them out thoroughly and lubricate with grease before you use the tester.

The light source is my adaption from materials that were at hand. The bottom lamp socket holds an adapter for a 7 watt clear lamp that I frosted with emery dust.

The ring of brass attached to the socket was a cover from a salvaged metal container similar to 35 mm film cans. A quarter-inch hole was made in the cover for aligning with the filament and covered with frosted cellophane tape; aluminum foil lines the inside. A metal bracket is attached by epoxy to hold single-edge razor blades by the slotted holes. I removed gripper edges on the blade by spreading them with a knife and pulling them off; then I trimmed them with snips and smoothed on an oilstone. The holes in the bracket which holds the blades are drilled and threaded.

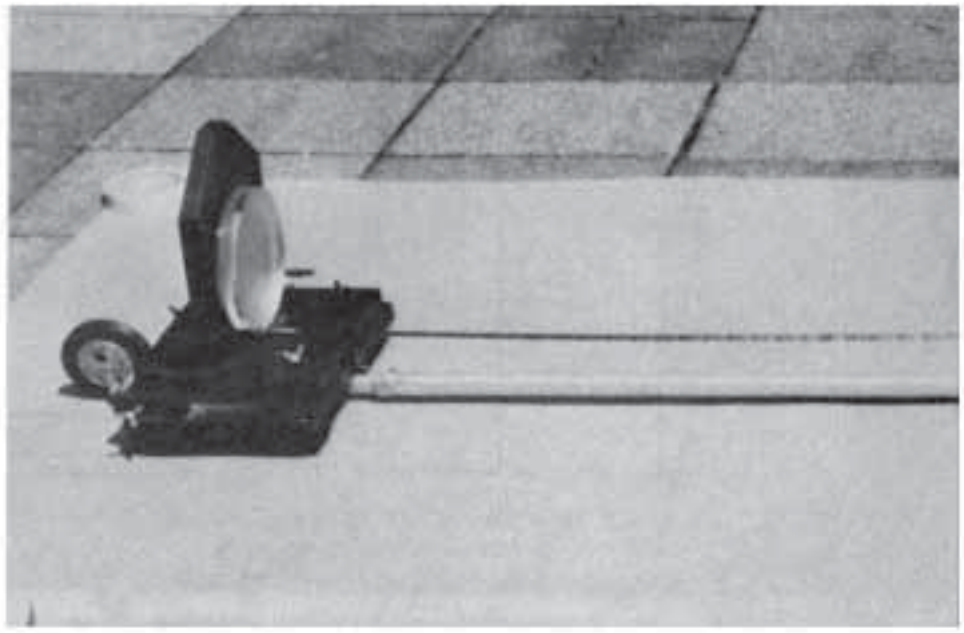
Mirror Stand

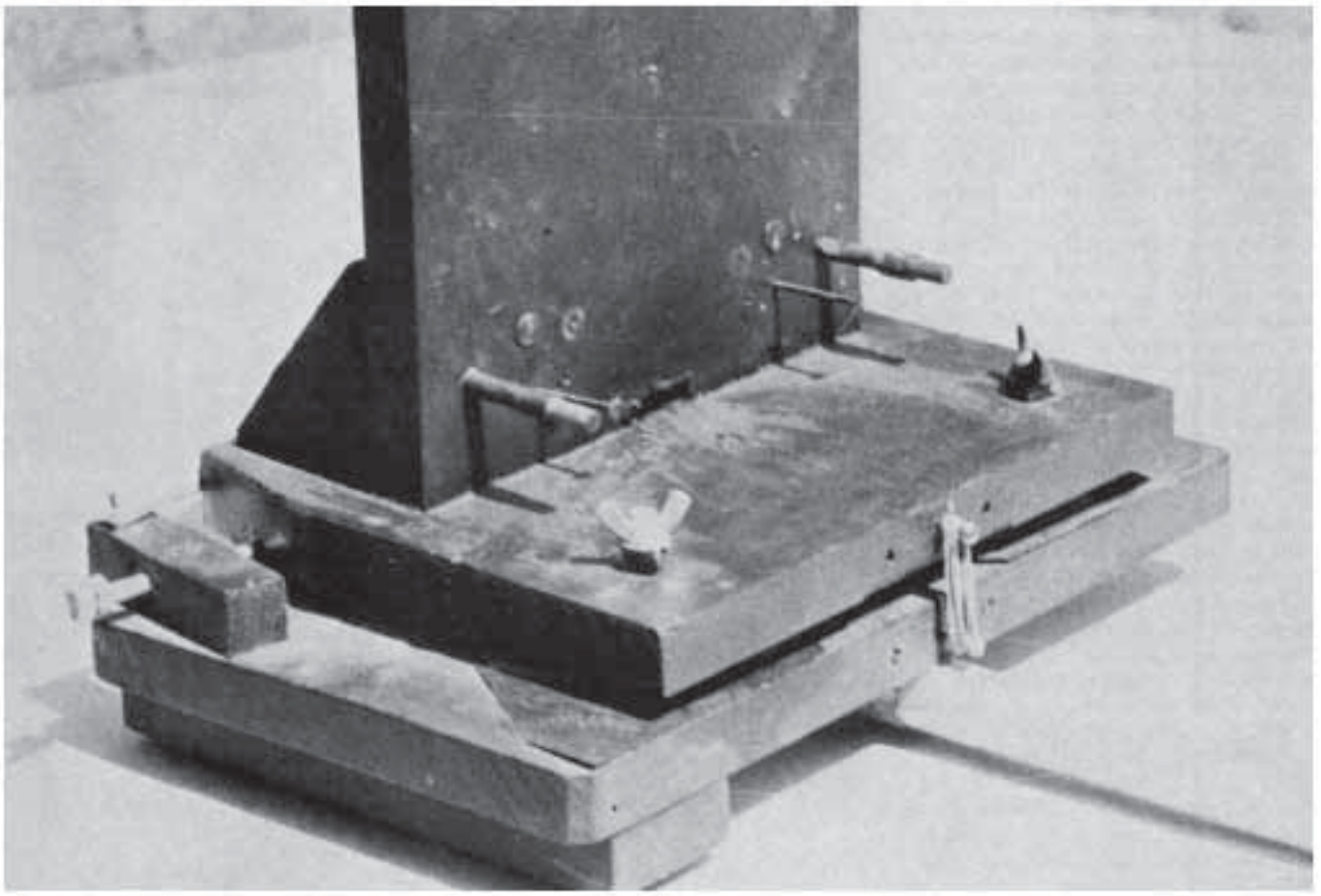
The adjustable mirror stand holds a mirror in the conventional way, but is supported at three points over a base which in turn is raised by 1 x 2 strips and pads on the underside.

The platform has a vertical stand with pegs to hold the mirror and swivels horizontally around a wood screw centered near the front edge of the mirror. It is moved by a thumbscrew working through a T-nut at the back corner and is restrained by a few rubber bands. Three thumbscrews turning through T-nuts in the bottom side of the platform elevate or tilt the platform over the base for vertical orientation.

The Connection

Telescoping sections of 1" and ⅞" lightweight aluminum tubing are strapped to the underside of the tester board and the mirror stand base. The larger tubing slides loosely over the smaller, but can be held securely when desired by squeezing the split ends of the larger tube with a





hose clamp. I added a steel tape (with one end fixed to the tester) to measure the distance to the face of the mirror on the stand. It's out of the way and ready to give the total distance with correction for both ends.

How is this arrangement handier than usual?

•The lever arm motion provides quick comparisons of the radii of curvature of mirror shadow differences. Read these from the .01 scale on the rule, then multiply by the lever reduction (1/10th) to get the knife-edge travel.

The quick transverse motion of the knife-edge has large range for analyzing shadows, and the edge is adjustable to pick up the slit image at any place on the mirror. It can be made parallel for testing with Couder masks.

The lamp cover swivels to aid in bringing the slit image into the range of the knife-edge after the mirror is worked on and replaced. The width of the light slit is adjustable, including opening wide for initial line-up on wet ground surfaces to get rough radii.

•The mirror stand provides a firm holder needing only minor adjustments to realign the mirror with the tester when some displacement does occur. The change is positive and controlled, superior to any loose fixture.

•The telescoping tubing supplies stability to the whole system while allowing easier and positive adjustments over a long range of distances to determine radii, and when clamped firmly holds against accidental movement. I've used a combination of lengths up to 15 feet. The steel tape supplies an instant check of distance, and it is detachable for other projects.

This combination of three things has saved me lots of time and has been worth the effort of constructing it many times over. And it keeps the fun in mirror making.

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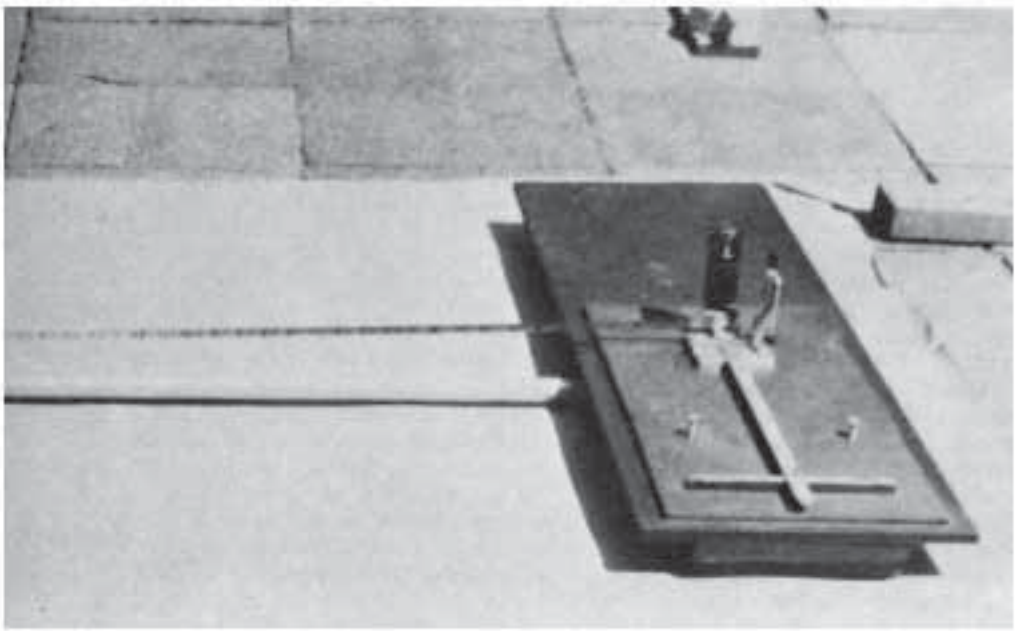


Many fine optical elements perform poorly. Often the user blames optics — not knowing that performance can be degraded by other important factors which, if corrected, would result in a fine instrument.

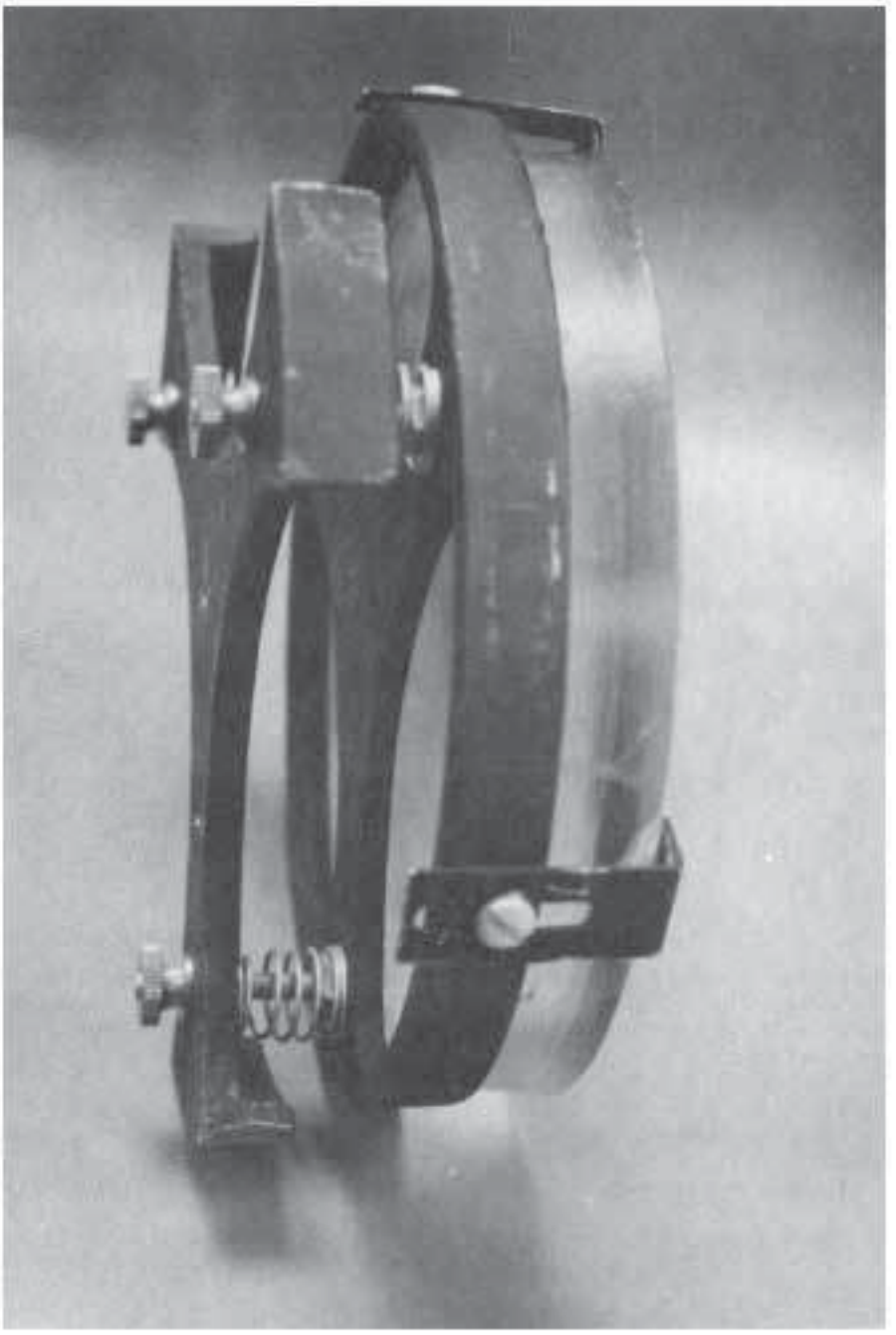
The factors that control quality are 1.) mechnical-constructional features and 2.) the alignment of the optical components. While improper collimation often is the result of mechnical-constructional design, it must be recognized that even the finest optical mountings need a practiced and experienced eye to align the optical path. Careful consideration of telescope operation will show that if a tube assembly has been properly designed and fabricated and aligned, then optimum optical performance should be achieved. Even other mechnical problems of axes alignment and mount rigidity will not change this situation.

Telescope makers in the mid-30s had information on mounting optics better than we have today. Telescopes held alignment for much longer periods of time even when transporting to observing sites. Let us therefore examine the conditions of how telescope optics, in particular mirrors, are mounted and used in today's telescopes, and then seek different approaches to improve the situation, including some that will be from the past.

Hobbyist mirror mounts, both purchased and homemade, are generally bulky. They take up too much room and add to the tube length. But most important, they don't contain the optics in continuous alignment. Many of the commercial mirror cells use spring loaded adjustments, with the threaded rods which control the pressure on the springs in oversize holes that permit easy tilt. These allow the mirror cell to shift under shock loads in transportation. Vibration in handling can also cause the adjusting nut to rotate, disturbing alignment.

Mirrors fit their cells loosely. A sloppy fit allows shifts that disturb alignment and high performance. This includes both radial (sideways) and lateral (forward and back) motions in the cells. Any obstruction on a mirror face causes diffraction and reduces detail seen on low contrast objects; and many cells have restraining clips over the mirror face that are many times longer than necessary. Possibly the large clips are to insure that a mirror with a sloppy fit will not fall out of its cell (!) if the tube is positioned so the mirror end is higher than the eyepiece end.

Many mirror cells are not adjustable for tube size. This again limits the worker to a tube size that fits, or is very close to fitting, a tube that has been selected by the seller. (I've seen some unusual collections of washers placed between a cell and oversize tube creating a situation that could never lead to continuous alignment in handling and transportation.) The only proper solution is to have a solid spacer, aluminum or phenolic, placed between the cell and the tube wall.



Mirror cells with adjustable feet for various tube sizes are available from some vendors and don't limit the telescope maker to a certain tube size or make him resort to securing special spacers. But if the locking bolts on these feet loosen up, then yet another source of poor alignment has been introduced.

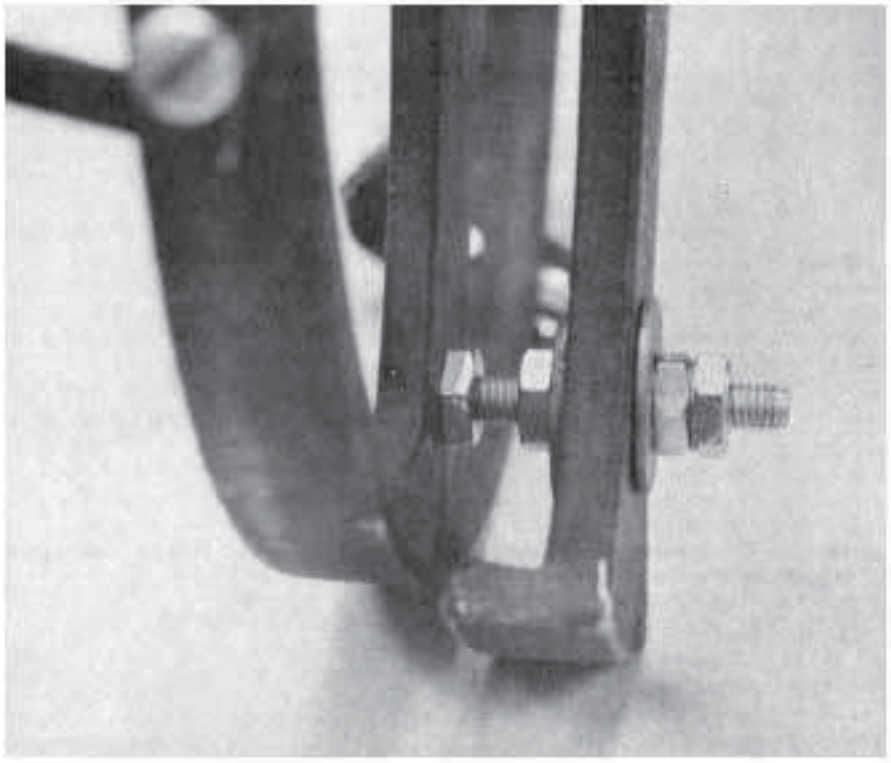
One of the hardest adjustments to master on a mirror cell, especially for the beginner, is the three-point mount system. It makes centering a chore — adjusting two diagonally moving images to finally get the secondary mirror centered in the tube relative to the primary mirror.

Without securing a new cell, what can be done to improve the one already in the telescope? One of the most important steps is to eliminate the spring adjustments; another is to throw away any butterfly nuts that may be on the back of the cell for adjustment.

These type nuts are there for easy adjustment because the cell is expected to continually lose alignment in handling; they serve no useful purpose otherwise.

Currently available mirror cells are not adequate. Here's how to make them better.

Better Mirror Cells



Butterfly nuts are a temptation for some human nut, when you aren't looking, to wonder what would happen if they turned one of them, and then proceed to do so!

Find the thread size on the bolts and buy nine hex nuts to fit the rods, plus six washers to be placed under the nuts. Now take the cell apart. Throw the springs away and replace them with a nut run down each rod to within four to six threads of the bottom so adjustment can take place in that direction. It may be necessary, if the threads don't go all the way down the rod, to get a die and cut them completely down the rods. Place a washer over each nut and then replace the rest of the cell on top of the washer. A second washer is put on each post and another nut is threaded down the rod and snugged down against the washer.

Make adjustments by loosening either nut and tightening the opposing one. This will tilt the mirror — but now a positive location is achieved after each change. If you have a workshop, turn three little disks of aluminum, drill, tap, thread, and place them between the cell parts. Their larger size allows you to loosen up this partially hidden nut more readily. Once alignment is obtained, place the final nut over the exposed one as a locking nut to prevent accidental loosening.

It is also possible to have two nuts at the bottom of the threaded rods with the lower one brought up against the upper one locking it in position. If this is done, it should be possible to remove the upper nuts, lift off the mirror and its cell, then replace it and have the same alignment as before. Without the extra locking nut, the single bottom one can turn in handling and cause the alignment to vary.

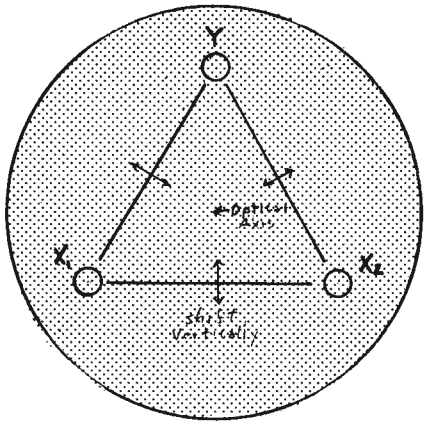
The separation and amount of shift you can expect in the alignment of a mirror cell has not been discussed and perhaps now is the proper time to do so. A great many mirror cells have 1/2" to 1" of space between cell components, a total waste of room which increases the tube length. Actually, 1/16" should be more than sufficient, a ⅛" overkill, while a ¼" or more would indicate a workman who can't read a ruler or lay out hole positions! Regardless of the cell design, the front and back components should be brought parallel to each other before installation in the tube, thereby putting the mirror face square to the mechanical axis of the tube (or reasonably close to this condition).

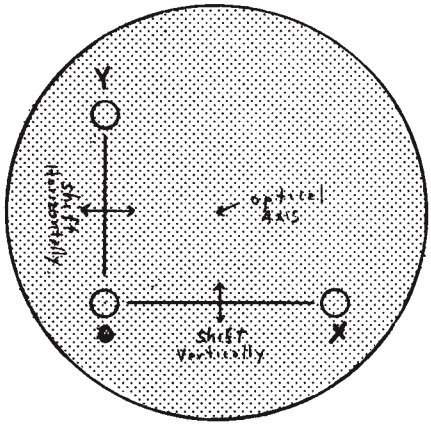
With modern cast mirror blanks and careful work in putting the curve in the mirror, the glass disk should be reasonably parallel. Tilt adjustment, therefore, should take very little shift and probably will average about 0.062" at the most. In any case, it should be obvious that you don't need a great distance between cell units, especially in professionally made cells, and you should expect to achieve alignment in shifts of not more than 0.015".

As far as adjusting legs to fit various tube sizes are concerned, once a proper fit has been found, don't depend on a bolt holding the spacing. Epoxy the two pieces together.

The bolt can be retained (if you wish) as a "safety" device, as many amateur workers don't obtain a strong bond when using such cements. ➤

Triangular and Orthogonal Support Systems





(Unless the surfaces are chemically clean and roughed up with sandpaper, most epoxy cements are not reliable and can let go with time. And unless the metal surfaces are very smooth and even, don't use any of the so-called "wonder" one drop cements. They don't work on irregular surfaces and depend on the surfaces to be matching to very close tolerances.)

To center the mirror in its oversize cell, appropriate shims (thin cork sheeting is excellent) must be placed between the mirror edge and cell wall. Don't use anything that is hard and unyielding in contact with both surfaces.

There should always be a gap between the shims and mirror edge. A good criterion is the thickness of a playing card, about 0.008", as the maximum clearance — use a gauge for setting spark plug gaps for "mike-ing" small distances such as this. A similar distance should be set between the face of the mirror edge and any clips over the mirror face. Once the mirror is restricted in movement in the cell, you can cut back the clips so they extend no more than 3/64" over the mirror face.

One other mounting point should be checked: the attachment of the cell to the tube. The holes accepting the bolts should be snug. Loose and sloppy holes let the cell shift in handling. If they are loose, place a lock washer between the washer and clamping nut and tighten the assembly with as much pressure as can be exerted without damaging the tube.

An interesting question now must be asked: What have these modifications cost you? A little time in exchanging springs for nuts, but for a hobbyist, time is the least expensive thing. It would be surprising if the total reached two dollars — and even in this period of high costs, this is something anyone can afford.

Perhaps the most important question is why don't the many vendors who supply cells and assembled telescopes make similar changes in their equipment? Surely it can't be the cost — and it's hard to imagine that they have too many springs on hand to justify scrapping them!

(Frankly, it is not possible to speak for others in a situation of this kind, but you can surely ask before buying whether a vendor can guarantee with a certainty of 98% a mirror cell, or telescope, that will stay in alignment in transportation and handling. Nothing is perfect, especially anything mechanical, but it would seem that the figure of 98% is a reasonable compromise with reality. I hope that as soon as current stocks are exhausted, vendors will seriously consider improving their products. It can do nothing but help everyone concerned.)

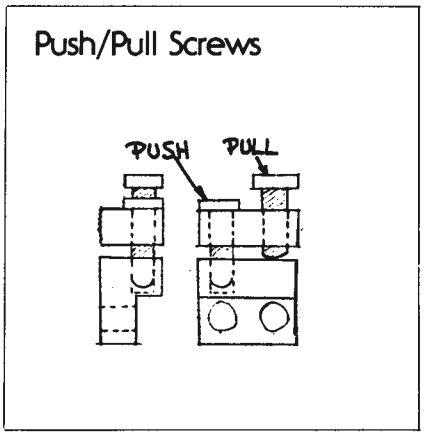
How to Build a Better Mirror Cell

There is a form of mirror support that uses three points of control in alignment, yet allows orthogonal adjustments. The image shift takes place in the horizontal "X" plane and in the vertical "Y" plane. The image shifts in the old-style mount have a movement in which the "Y" nut shifts the image of the diagonal in the "Y" plane around the X^1 and X^2 points. However, shifting either X^1 or X^2 shifts the image either around the Y-X^1 or the Y-X^2 axes — and not in the "X" plane as you would desire. If you're actually adjusting a mirror, you'll think you're going nuts!

To correct this, we can switch to the type used by many professional companies who supply mirror mounts for laboratory use. Note that the three points are no longer equally spaced from one another, and that two of them are now at right angles to each other. A movement of nut "Y" will shift the diagonal image in the vertical plane around the X-O axis, while a shift of the "X" nut will move the image in a horizontal plane around the Y-O axis.

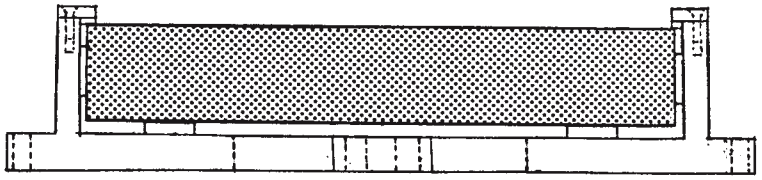
The support point "O" is not used in alignment in this form of support but acts as the pivot point for both the other axes. Now when a change is made, you know just where the image of the diagonal is going to shift. If you like a three point adjustment on your mirror cell, then the next time try this form of construction. You'll never go back.

It isn't necessary to have two plates in a mirror cell. Back in the 1930s, it was common to use one plate in a push-pull type of mirror tilt adjustment. The method is just a top cell plate with extended lugs outside the cell proper. In the lug extensions, you drill two holes, one a clearance hole for a bolt and the other a threaded bolt hole. The bolt extending through the clearance hole engages a threaded hole in a holding ring

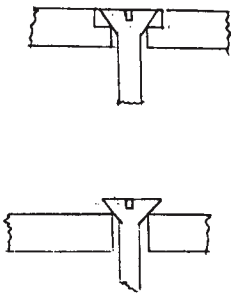


or lug located at the bottom of the tube. Its action is to pull the two pieces together. The bolt through the threaded hole is a push action against the tube mounted ring or lug. The two bolts can be located on a line running through the mirror center (radially and the long way), or they can be located side by side; the results are the same.

The Basic One-Piece Mirror Cell



Swivel Systems



The advantage of this system is that you can remove the pulling bolts and the cell from the tube, but when it is returned and these bolts tightened down, the push bolts will relocate it exactly in its original position, retaining alignment.

This form of mounting is recommended for its positive positional accuracy. As the lugs holding the bolts extend beyond the mirror cell and need room for working, they won't fit in small tube diameters without tube modifications. (We'll get back to this later under tubes.) Back in the 1930s, a 6-inch telescope had an 8-inch tube for holding the optics and the lugs were engaged by clips inside the tube wall. Even better, a metal ring inside the tube to which the cell was fastened also stiffened the tube in handling.

The drawings of the one-piece cell show the simplicity of the castings, if they are made this way, with a minimum of machine work to put them in operating order. Individuals who don't have machine shop facilities can easily fabricate such a cell with simple hand tools. Using a sabre saw, the base shape can be cut out, then smoothed with a file and sandpaper. The vertical posts are bolted to the bottom plate and careful work with a hand drill will locate the holes for the push-pull bolts. Incidentally, if you're not familiar with working with a power drill, it might be advisable to use a hand drill to make the holes. It's slower, but you can keep control better. To cut down work for the restraining clips on the top of the posts, we suggest that only one screw be used to hold the metal piece down with a pin through both pieces preventing them from rotating. Another approach is two pins with a single screw between them.

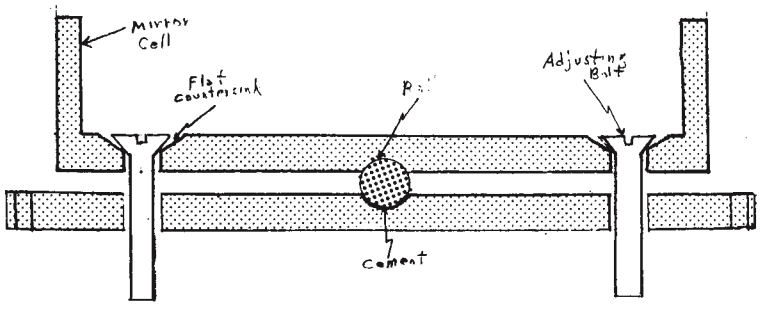
In locating the vertical posts to prevent the mirror from shifting sideways, allow about 0.008 inches between the cork and edge of the mirror. The same cork and edge of the mirror. The same clearance is set between the cork on the clips and the top of the mirror face.

For many years I have used, and still encourage others to use, two types of mirror cells that have a four point adjustment setup. Although they don't exactly result in the tilt motion being on the mirror face, the situation is closely approximated. The simplest type is a ball swivel type arrangement. Here a ball is put at the center of both mirror cell plates and four bolts attached to the bottom of the mirror cell. They extend through clearance holes in the bottom plate to provide tilt adjustment. It is a push-pull working arrangement: by loosening one nut and tightening the opposite one, you tilt the mirror on the central ball. When alignment is reached, the nuts are tightened down and locking nuts on top prevent any movement.

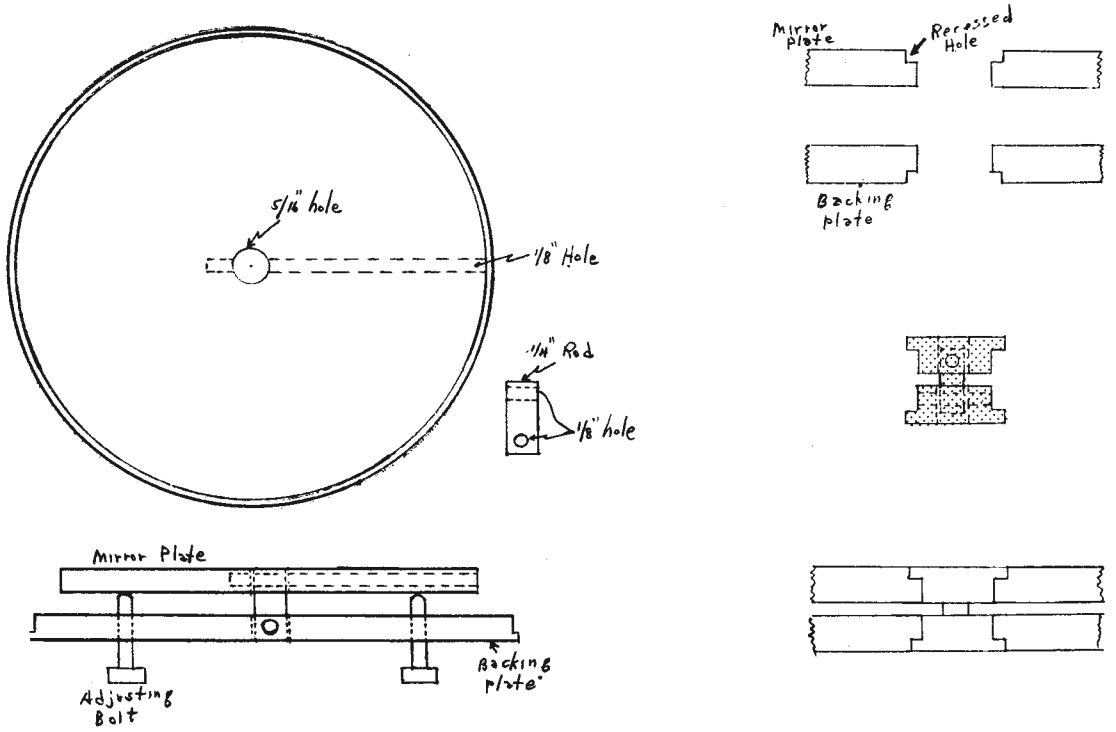
The ball is mounted by making a depression in the center of the back plate (if available, the proper size ball nose drill is excellent) and cementing the ball into this depression. A similar depression is placed in the back of the mirror cell but not cemented as the cell must remain loose to tilt on the upper ball surface.

If tilts are small, then the bolts can be set square in the upper plate, but if large movements are required, then the nuts will not sit down flush on the rear of the back plate when tightened down. To avoid this, and to eliminate the need for ball surfaced adjustments on the bolts, it is possible to use the under surface of a flatheaded bolt as a bearing surface. Two approaches are possible: the first is to drill an oversize hole for the bolt head and let the taper on the underside of the head slip around on the edge of the hole. It's important that the hole in the bottom of the plate be larger than is recommended as a clearance hole for the bolt. The second approach is to cut a deep countersink that has a flatter taper than that on the underside of the bolt. Use a countersink with a 100° or greater taper and select a bolt with a taper of 80°. In either case, it will now be possible to allow the bolts to tilt in adjustment so the nuts will sit flat against the back of the unit.

Ball-Swivel Cell



Universal (or Knuckle-Joint) Cell



The next system is one I've used on the primary mirror of my 4¼-inch Schiefspiegler primary mirror. This scope has kept alignment so well that in 15 years of transportation to star parties in my car it has required retouching of the alignment no more than half a dozen times. The system is basically one called a universal or knuckle joint. It is easy to build.

For the 4¼" mirror the plates were ¼" thick and in the center of each plate a ⅜" hole was drilled. From the edge of the plates a hole ⅛" in diameter was drilled so it passed centrally through the large hole and extended ¼" into the far side. A rod 5/16" in diameter and ½" long was then drilled with two ⅛" holes at right angles to each other and close to the ends of the rod.

To assemble it, a ⅛" pin was placed in the hole in the side of the cell plate and pushed through the central hole into which one end of the rod had been inserted. The same thing was done to the other cell plate with the pin and its shaft at right angles to the first one. Bolts through the back plate push on the front one, holding the mirror, and by locating the bolts so they're at right angles to the pins, the tilts take place on the pin axes. One plate tilts around one pin and the other around the other pin at right angles so the shifts are distributed around two axes separated by ½" — but this is still close enough to give a sensitive adjustment relative to the center of the face of the mirror. Locking nuts on the adjusting bolts make sure of continued alignment over long periods of time and handling.

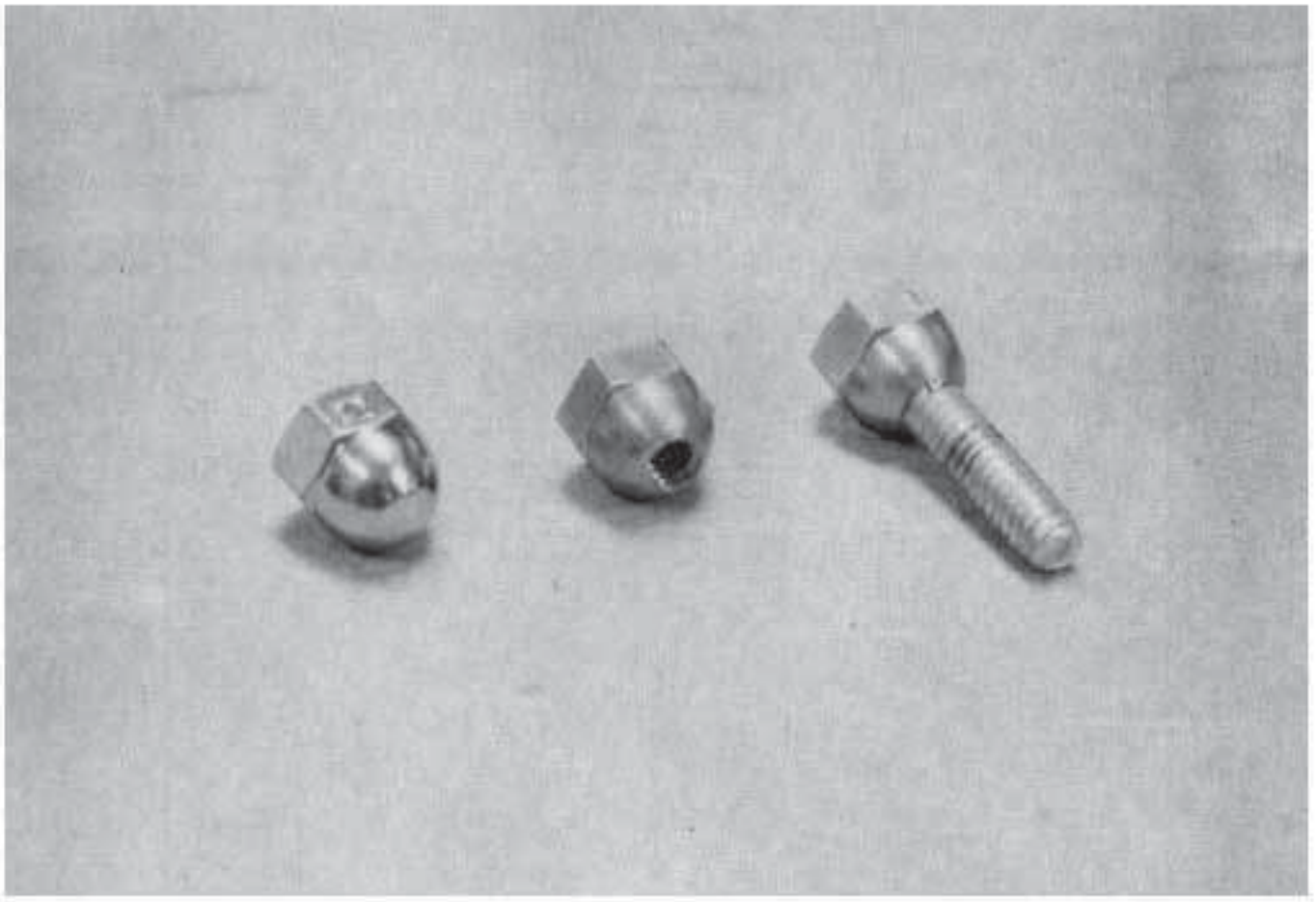
Is it possible to modify your present cell to this knuckle type mount? It certainly is! For a cell that has a closed center area (a little careful thinking will let you figure out how to do a similar modification on other type cells), some machine work is necessary. In the top of the mirror cell, a flanged cutout is made, as shown, with a similar cutout in the bottom of the back cell plate. Two machined hubs are made with a flanged top that fits the large opening cut in the mirror cells and is a snug fit in the smaller bottom part of the central hole. In the smaller portion of the hubs, drill a pin hole extending through the center of the hub axis.

Through the center of the hub a ⅜" hole is drilled to accept a 5/16" rod in the same manner as described for the original cell. The two hubs can be epoxied in their holes or left free as the pressure of the adjusting bolts will automatically pull them tight in their receptacles. Once tightened, there is no way they can come loose unless the bolts themselves loosen up. All that remains to make the unit workable is to drill and tap four holes for the adjusting bolts.

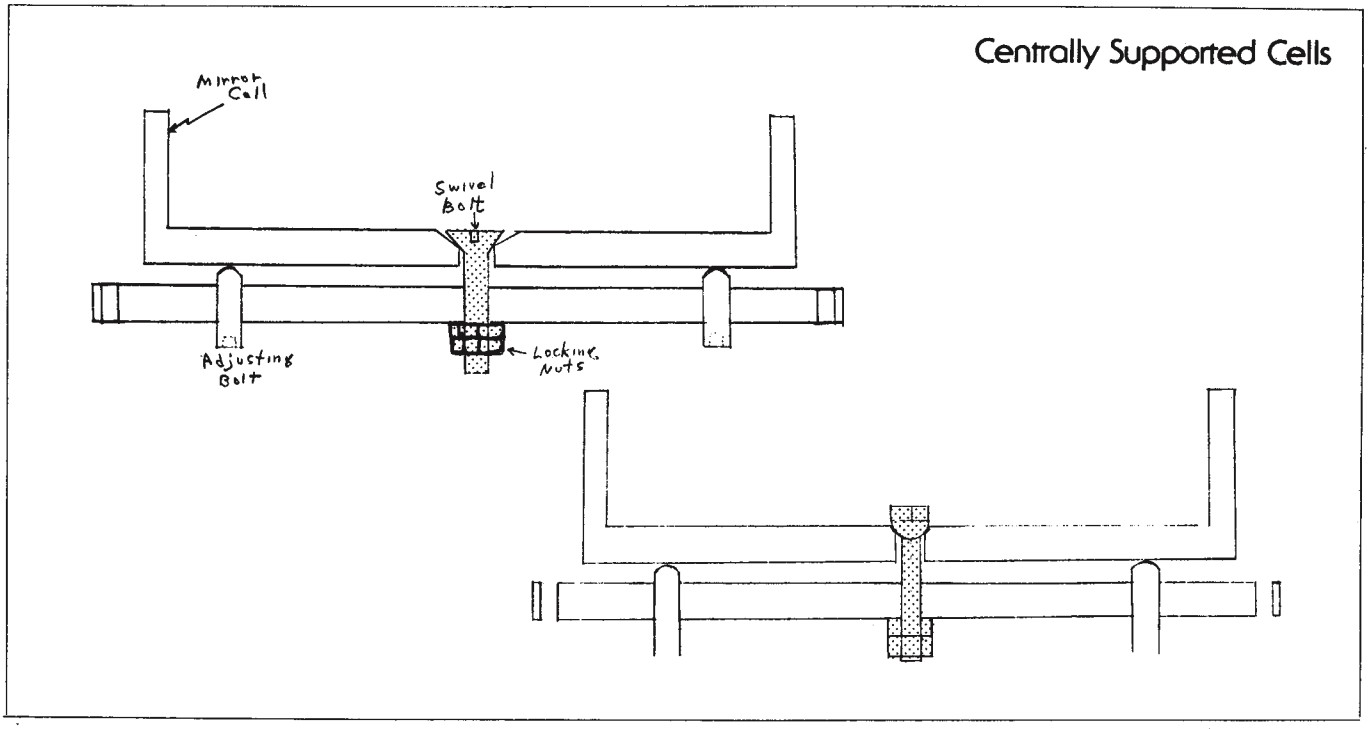
There are two other centrally supported adjustment systems. The first uses a flathead bolt with a countersink taper on the underside as a pivot point. As a center swivel, use of two countersunk surfaces is recommended rather than the oversize hole approach. It's not necessary to have a restraining cover on the opening over the bolt head as the pressure of the adjusting bolts will hold the assembly together.

If a worker wishes to construct a ball-type swivel, those familiar with machine supplies will soon recogize items made for other applications can be adapted. One example that has been suggested to me is a ball-linkage used on a car carburetor. It is also possible to obtain a steel ball and silver-solder a threaded shaft to it and cut a depression in the mirror cell with a ball nose drill for the ball to ride in.

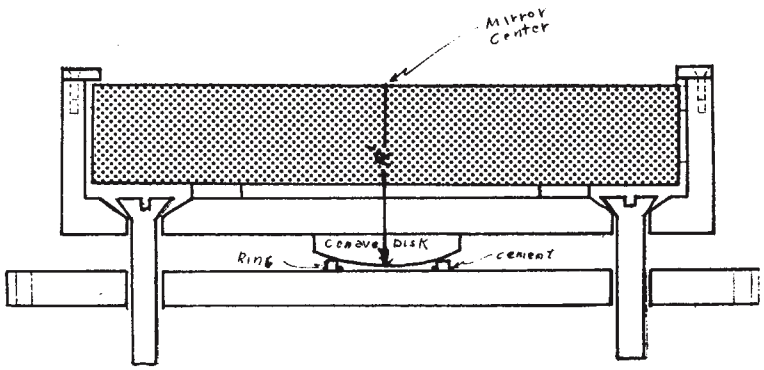
Another design was suggested to me (as a substitute for a ball bearing with a threaded shaft attached) by Kenneth Novak several years ago in correspondence on mirror cell improvement. The



piece is a cap nut used on the ends of straight shafts to improve appearances (they are often found on professionally made telescope assemblies). The ball portion of the piece can ride either in a round receptacle made by a ball nose drill of the proper size, or it can rest on the edge of an oversize hole drilled in the mirror cell base. The cap nut is thicker than necessary, but you can cut it back by either removing the unrounded portion with a hacksaw, turning it off in a lathe, or, with a little hard work, file it off. Be sure that the top of the swivel clears the mirror back.



Ideal Swivel Cell (Pivots about mirror surface)



In the mirror cells we have so far discussed, the swivel action has not taken place around the ideal point — the face of the mirror! However, this is easy to arrange. Add the thickness of the mirror, the supporting pads behind the mirror, and the cell. On the back of the mirror cell, carefully centered, fasten a disk upon which has been shaped a convex surface.

If the radius R′ is equal to the sum of the thicknesses previously determined, plus the thickness of the added disk, the mirror will pivot about its face. To keep down the total thickness of the cell, the thickness of the added disk should be just sufficient to allow shaping of the convex surface plus 1/16″ for edge thickness.

On the inside surface of the back cell plate a ring is fastened which has a diameter 70% of the convex disk on the top cell plate rear surface. A nylon or teflon ring is an ideal slippery surface for this purpose. To obtain more than a point contact, cut a bevel on the inside of the ring. Four bolts extending from the rear of the top cell and passing through the rear plate provide the necessary tension through locking nuts to hold the assembly together. Loosening and tightening opposing nuts tilts the mirror around its face to achieve alignment.

With a compound optical system with a hole in the mirror, make the convex disk larger and provide a corresponding hole in its center for the light to pass through. The swivel ring is also made correspondingly larger in diameter.

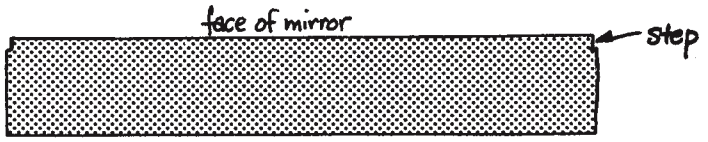
All tilt adjustments made around the center of the mirror axis are more sensitive to image movement than a case where the tilt is controlled at the edge of the cell. Consequently not much movement of the adjusting nuts will be required.

Mirror Clips

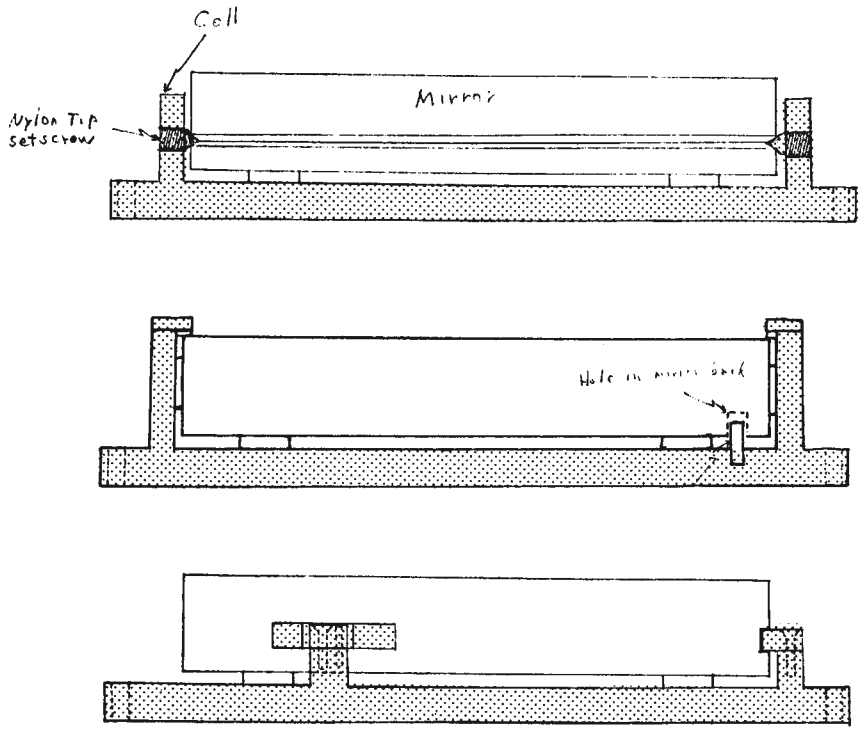
In a diffraction limited telescope, the ideal situation in mirror mounting is one in which there are no clips extending over the face of the mirror. If you're willing to sacrifice a little aperture, then the retaining lip method of mounting will work splendidly. In this method the clips will not only keep the mirror from falling face forward but will also keep its sideways motion restricted.

To prevent warping in periods of

Grooved-edge Mirror



Unobstructed Mirror Clip Systems



extreme temperature changes, be sure there is at least 0.005" of clearance all around the clips. The retaining lip can be cut with a carborundum wheel with plenty of lubricant to keep the glass cool during cutting. While the use of a lathe is convenient, an enterprising TM will devise methods of holding the glass and rotating it while letting the cutting wheel shape the glass.

At the Mid-States Regional meeting of the Astronomical League in St. Joseph in early June, I heard of a Kansas City, Missouri telescope maker who mounted his mirror by cutting a groove in the edge. Pointed setscrews contacted the groove to locate the mirror in the cell and hold it in position. Such cutting, in fact any cutting into the glass, should be done before grinding to help minimize any strain that might be induced into the glass and which could be relieved in surfacing.

To prevent temperature changes causing pressure on the edge of the glass, it would be advisable to use nylon tipped setscrews (and not metal ones) for this kind of mounting. Only three setscrews should be used to restrain the mirror in order to preserve the principle of a plane of reference in holding the mirror. If more than three are used, then one loses this ideal condition.

Many people don't have motors and lathe facilities and therefore can't apply this approach of cutting a circular groove in the mirror edge. However, there is a simple approach that makes this unnecessary. Using either a carborundum stone or a piece of metal, it is possible to grind three slots in the mirror edge to hold restraining bars, eliminating edge clips in the mirror mount. It's a good idea to cut any grooves or slots closer to the bottom of the mirror edge to reduce the chance of induced strain affecting the surface that has been ground and figured. These kinds of mounts should be ideal on TCT instruments where any face clips reduce the advantage of using an unobstructed mirror system.

Another error can occur, especially in cells that hold a mirror in a sloppy manner, if the glass rotates around the optical axis. If the mirror back and face are perfectly parallel, this is of no consequence, but molded glass blanks are not parallel and few workers take the time and trouble to make them so. Restricting the mirror from any rotation assures continued alignment.

(Professionally made mirrors should have the surfaces made parallel with a diamond wheel surfacing machine. With such an instrument, it takes only a few minutes to cut the surfaces flat and parallel. In shops where I have had such machines, I've made it standard policy to surface all mirror blanks in this manner.)

A simple, yet efficient way to prevent mirror rotation in a cell is to drill a small hole in the mirror back surface to a depth of about ¼" and install, at a corresponding point in the mirror cell mount, a pin which engages this hole. Be sure to do this before grinding the curve to eliminate danger of induced strain from the drilling.

A simpler method is one that involves attaching lugs to the glass and cell to restrict rotation. This approach is simple, but requires very special attention.

Fastening anything to a surface of a mirror requires the use of some form of cement. Today the use of epoxy material is popular with many. Before going any further, one thing must be made perfectly clear — under NO circumstances should any material be used which has HEAT involved in its curing or setting! (This observation or conclusion was reached after I spent many years of experiments looking for ways to cement mirrors to supports in the mounting optics used in simulation devices.)

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Optical Testing with the

WIRE TEST

The Wire Test is a method used by professional optical shops for the surface testing and evaluation of large mirrors. It's generally not even known about by TM hobbyists although it has been in use since 1968. The test was discovered by James Kent while he was working for an aerospace company (which made it a proprietary subject and restricted information on it), but it is now finally removed from the restricted list.

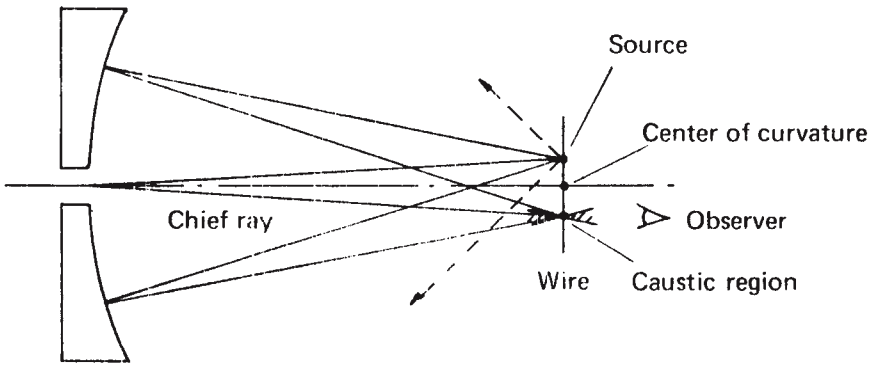
The most extensive use of this test on mirrors over 60 inches in diameter has been at the shop at the Optical Sciences Center at the University of Arizona in Tucson.

The test is similar to the Foucault test, but instead of seeing shadows covering the face of the mirror, you see a thin ring of darkness progressively moving across the face of the mirror as the light and wire move towards or away from the mirror. The longitudinal readings between zones enable the worker to determine the surface profile of the mirror using methods very similar to the Foucault test.

The edge of the wire represents the leading edge of a knife-edge in the Foucault test but, unlike the knife-edge test, there is no large distracting shadow over the rest of the face of the mirror. Diffraction effects are also somewhat more uniform and less distracting.

In the wire test, the light source and wire move together. The holder for them must be able to move along the optical axis of the mirror, and the wire and source must move perpendicular to the optical axis — exactly as in the Foucault test. The construction of a test unit is quite simple. Basically, a thin piece of metal 1/32" to 1/16" thick has two holes drilled in it (the top one about ¼" in diameter, the bottom one a ⅛" hole) as close together as feasible. A wire 0.004" in diameter is stretched across the top (larger) hole parallel to one side of the metal piece and centrally positioned over the hole. Over the smaller hole is placed a piece of shim stock with a 0.003" pinhole in it. You can illuminate the pinhole any way you want to, but the structure should be kept small so the eye can be placed close to the opening behind the wire.

No mask is used to indicate zones on the mirror face at which readings will be taken. It's easy enough to mark them on the face of the mirror with a felt tip pen, or better, place a wooden stick with pins in front of the mirror to indicate the zones. This approach is similar to the one presented by Wally Everest in *Amateur Telescope Making Advanced* (pages 9 and 21 through 23).



To test the mirror, set it up on its stand and place the wire tester close to the center of curvature of the mirror. Put the frame holding the pins over the mirror, carefully centering it. Corresponding pins each side of center must be equidistant from the center. Looking past the wire, locate the light bundle from the mirror. To insure that the tester is moving along the optical axis, align the tester base until, as it is shifted towards and away from the mirror, the dark circular shadow of the wire touches pins that are equidistant from the center of the mirror all along the path of travel.

The wire is thicker than the diameter of the paraxial pinhole image, so it isn't possible to determine the location of the "zero point." However, this is normally not important, because with fast mirrors the wire test is best, for the secondary obstruction covers the central area. For testing such mirrors, start the zonal pins at the edge of the secondary or diagonal obstruction. If the mirror has a hole in its center, then that edge naturally defines your starting zone.

As thin as the wire is, its shadow is broad. On the 60-inch University of Arizona mirror, its projected width just spans two pins one inch apart. Unless carefully selected, the wire and pinhole relation could limit the observer's ability to select enough zones in a test situation. Because of this effect, Don Loomis of Custom Optics (Tucson, Arizona) who supervised the application of the wire test operation when he was with the Optical Sciences Center, recommends this test only for fast mirrors. He does not consider it good for mirrors slower than f/5.

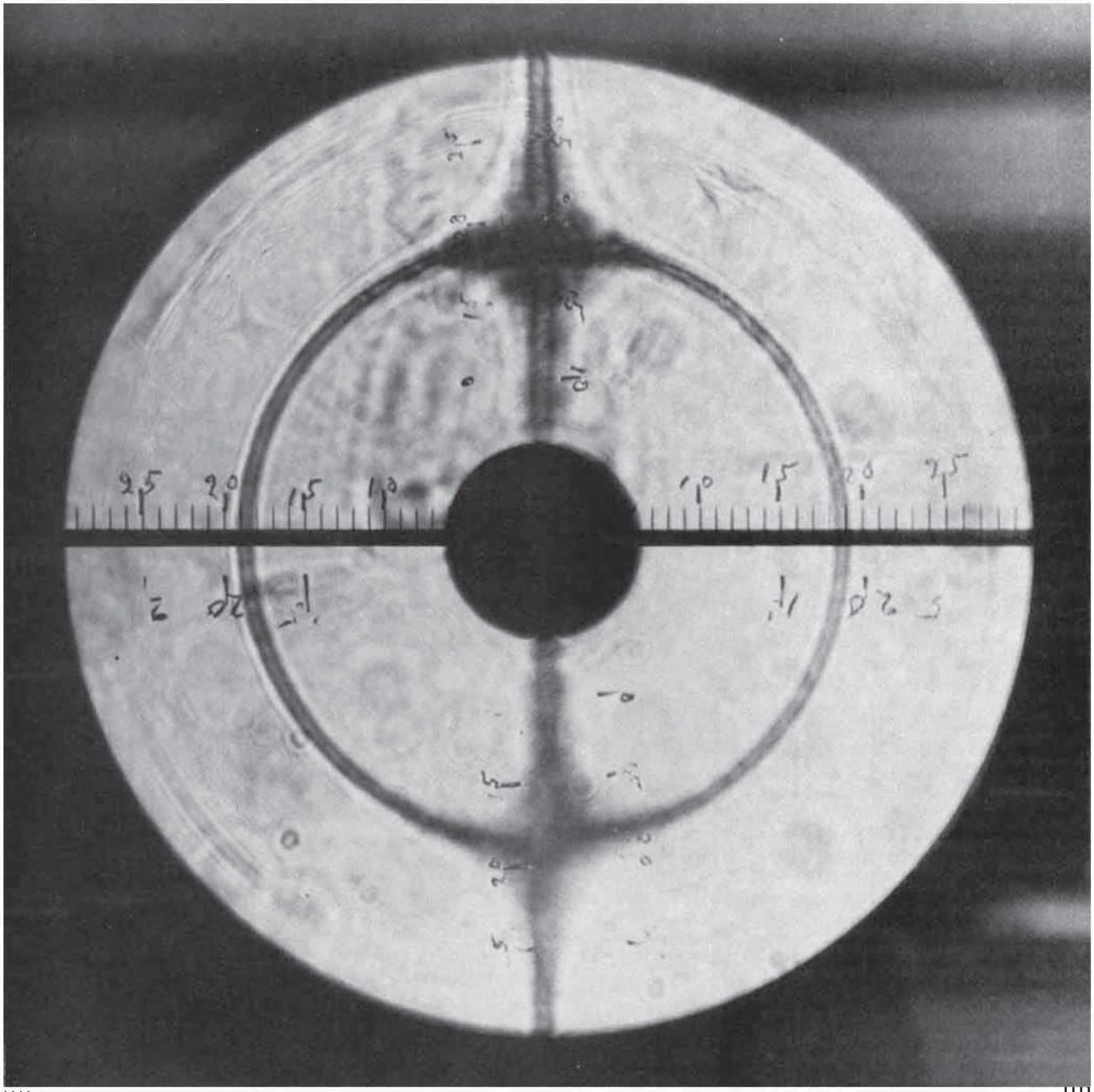
In testing, the mirror is seen fully illuminated except for two locations, a dark vertical band up the center and a dark circular ring. When the edge of the dark ring is placed on one of the pins, it determines the intersection of the normal with the optical axis for that point on the mirror and a reading of the longitudinal shift for that zone.

The wire test has advantages over the Foucault test in that the wire test lets the

Testing Mirrors with a Wire Test

With more and more telescope makers considering a large aperture mirror, the methods of professional opticians must be made available if those workers are to be successful. With large optics, the time-honored simple amateur methods are no longer adequate. To help these workers, TM will present articles from professional sources on large mirror fabrication.

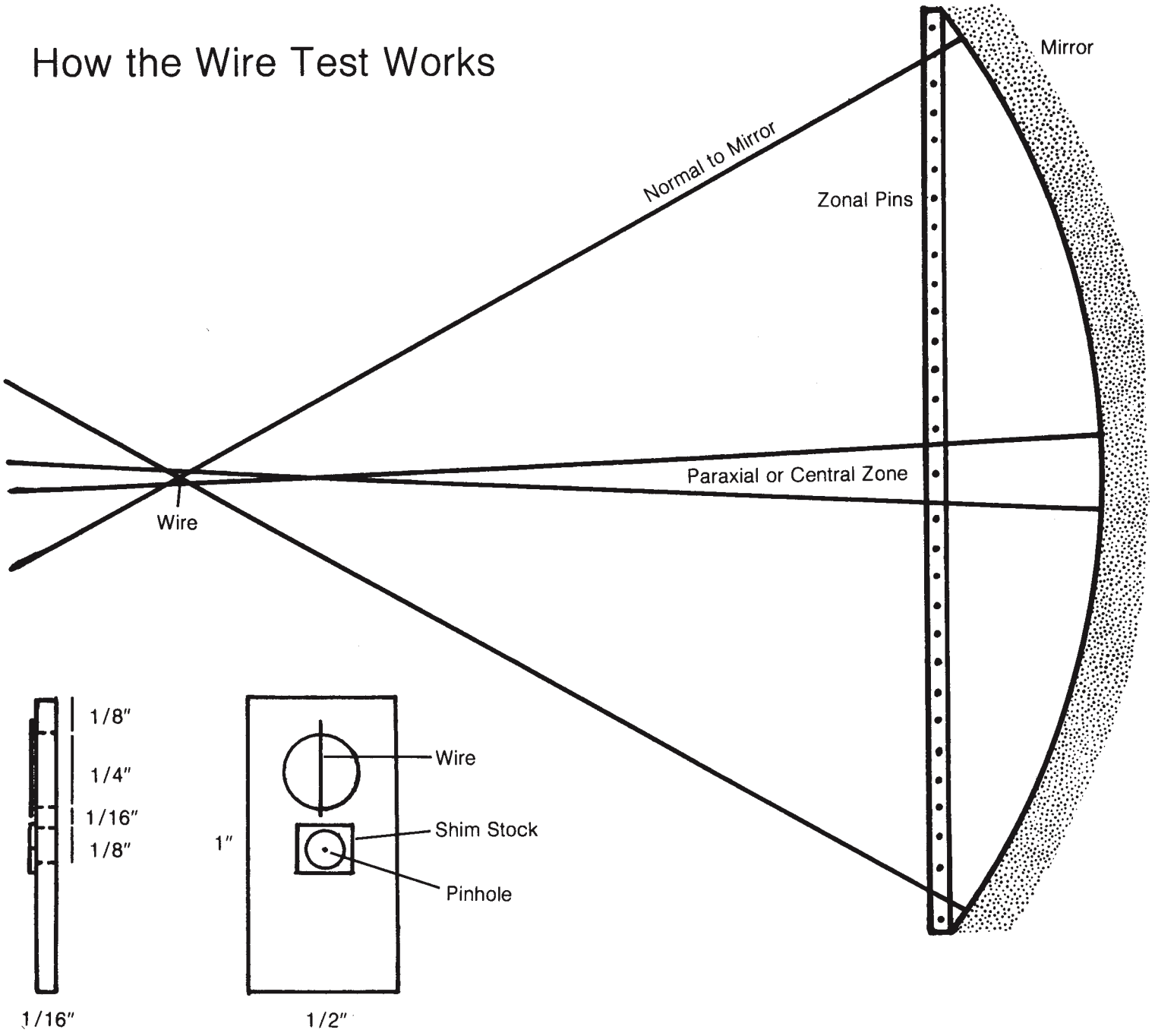
This material is taken from the *Optical Sciences Center Technical Report 79*, "The Design, Construction, and Testing of the Optics for a 147-cm Aperture Telescope," with the permission of the editor of publications.



Wire Test Theory

In the axial wire test, a vertical wire is inserted in the caustic region of the return beam when the mirror is illuminated by a point source near the center of curvature of the mirror (see the figure). An eye placed behind the wire will see a shadow projected onto the mirror for all rays blocked by the wire. If the mirror is a true conic of revolution, the caustic will be a figure of revolution about the chief ray. If the wire is positioned laterally to intersect the chief ray, the shadow will consist of a vertical straight line parallel to the wire and centered on the mirror. In addition, a circular shadow will also be produced that will be centered on the mirror. The circular shadow identifies the zone from which the reflected rays will intersect the chief ray at the location of the wire. As the wire is moved axially, the radius of the circle will vary. If the point source and the wire are located in the same plane and move together, the axial position of the wire as a function of the radius of the circle will map the axial portion of the *caustic of the normals* to the mirror surface. From this information, a profile of the departure of the actual mirror surface from the desired conic can be determined.

How the Wire Test Works



whole mirror face be seen, except for the dark ring being used to locate a particular zone. Another advantage is that diffraction effects are symmetrical permitting more accurate determination of the shadow to the pins. The principle disadvantage is that the width of the shadow band can mask small displacements of the shadow band, and consequently small errors in surface slope. In using the wire test you should also apply the Foucault test, passing the shadow over the face of the mirror to detect any such irregularities.

In running this test, you may have trouble in interpreting the central zone shadows. It's best to start with the outer zones and progress toward the center. When the inner zone readings become ambiguous or difficult, stop and make the analysis.

It is important to remember that no single test is completely satisfactory in every respect and this is why professional opticians use several in their work.

Several variations on the wire test have been independently discovered over the years, although in each instance the application was not completely reliable.

Don Conners, of Vancouver, Washington, in May 1969 wrote me of his experiments but erred in thinking it necessary to subtract the diameter of the wire (the mirror being tested was a 12½" f/5).

William Vaughn in Columbia, Missouri used a wire test in conjunction with "blinking dots" to determine his zonal readings. He placed ink points on the face of the mirror and then moved the light and wire back and forth over the spots. As the shadow moves over any particular one, diffraction effects cause it to be dark and then bright. He used the point where the dot remained dark but blinked on either side for his zonal measurement.

Experts at the Optical Sciences Center did not recommend its application in that form, pointing out that the edge of the shadow was the most reliable point of measurement.

The simplicity of the equipment and ease of application should attract many telescope makers to use this test, especially those making compound telescopes with fast aspheric mirrors. Since it is new, TM is interested in comments by our readers who try this test or experiment further with the pinhole and wire sizes.

Robert E. Cox

The properties of the axial caustic of the normals to a conic surface of revolution are remarkably simple. Because the system is rotationally symmetrical about the axis of revolution, we need consider the problem in only two dimensions in a meridional plane.

Let the axis of revolution coincide with the z axis. Then $z = z(y)$ will represent the meridional section of the conic of revolution. Explicitly it is given by

$$z(y) = \frac{y^2/R_0}{1 + [1 - (K+1)(y/R_0)^2]^{1/2}} \tag{1}$$

where R_0 is the paraxial radius of curvature and $K = -\epsilon^2$ is the conic constant for a conic of eccentricity ϵ. For a sphere $K = 0$, and for a paraboloid $K = -1$. If $K < -1$ the surface is a hyperboloid, and if $-1 < K < 0$ it is a prolate ellipsoid. If $K > 0$ the surface is an oblate ellipsoid.

If the distance from the mirror vertex to the intersection of the surface normal with the axis is represented by l, then it can be shown that

$$\begin{aligned} l - R_0 &= -Kz(y) && (exact) \\ &\approx \frac{-K}{2R_0} y^2 - \frac{K(K+1)}{8R_0^2} && (approximate). \end{aligned} \tag{2}$$

Moreover, the length R of the normal from the surface to its intersection with the axis is determined by

$$R^2 = R_0^2 - Ky^2 \qquad (exact). \tag{3}$$

If the actual surface departs from the desired conic by an amount $s(y)$, then the axial intercepts of the surface normals will depart from those determined by the above equations by an amount $\Delta l(y)$. It can be shown that the surface departures, s, can be determined approximately by

$$s \approx -R_0^{-2} \int y \Delta l dy + s_0. \tag{4}$$

The quantity s_0 is an arbitrary constant of integration. This approximation is valid if (a) $\Delta l \ll R_0$; (b) $s \ll \Delta l$; and (c) $(K+1)y^2 \ll R_0^2$. Item (c) is valid if $y \ll R_0$ (large f-number) or if $K \approx -1$ for any f-number. These conditions are adequately met in the present case.

In the implementation of the test, the value of K is given by the optical designer. Because the mirror has a central hole, the value of R_0 is obtained by measuring R for some zone radius y and then using Eq. (3).

The values of Δl are determined as follows. Let $l' = l + \Delta l$ represent the actual axial intercepts whereas l represents the ideal. Then, as a function of y, the wire test determines values of $w(y) = l'(y) - l'(y_{ref})$, where y_{ref} is an arbitrary reference zone. Then

$$\Delta l(y) = w(y) - [l(y) - l(y_{ref})] + \Delta l(y_{ref}). \tag{5}$$

The quantity $w(y)$ is the difference between the axial setting for each zone y and the axial setting for the reference zone y_{ref}. The quantity $l(y) - l(y_{ref})$ can be calculated from Eq. (2). The quantity $\Delta l(y_{ref})$ is undetermined, but its value, which is small, is a constant for all y.

The values of s are then obtained by the integration indicated in Eq. (4). The effect of the undetermined constant $\Delta l(y_{ref})$ is to introduce a parabolic component,

$$s' = \frac{\Delta l(y_{ref})}{2R_0^2} y^2, \tag{6}$$

to s. Small changes in s' correspond to changes in R_0 that are smaller than can be measured directly. Therefore, an arbitrary value can be assigned to $\Delta l(y_{ref})$ to flatten appropriately the s curve representing the departure of the actual surface from the ideal surface. In addition, the value of s_0 in Eq. (4) can also be assigned arbitrarily, which corresponds to choosing different reference levels in the vicinity of the surface of the mirror.

One particular application of the otherwise arbitrary choice of $\Delta l(y_{ref})$ and s_0 is the coordination of a given test run with the preceding one if an appreciable portion of the mirror remains untouched between the two test runs.

■

What's New?

new products of interest to telescope makers

Listings in this column in no way constitute an endorsement of any company or product. Manufacturers please note that each item will be confined to a brief description and specifications.

Interference Controls

"A new catalog from Electronic specialists presents their line of scientific and electronic interference control products. Protective devices are also included.

Typical applications and uses are outlined." Might be of interest to photometric observers. Ask for catalog 971.
Electronic Specialists, Inc.
171 South Main St.
Natick, MA 01760

Edmund RFT

Fork-mounted 6" RFT, f/4, 2-5/8" diagonal, 2" focusing mount, with fork mount and RKE eyepiece, $569.00. 30-day money back guarantee.
Edmund Scientific Co.
7782 Edscorp Building
Barrington, NJ 08007

Optical Glass

"New west coast glass molding firm, Bi-Optical Incorporated in Costa Mesa, CA offers mold pressed, slumped, fine and precision annealed, core drilled, and sawed optical glass in weights from 4 grams to 30 pounds. The firm carries molds ranging from ½" to 14" in diameter and maintains a machine shop where they can produce their own tooling when required."
Bi-Optical, Inc.
2044-D Placentia Ave.
Costa Mesa, CA 92626
714-642-9980

Mak Optics

"6" f/15 set of Maksutov optics includes 1/50 wave spherical primary and precision matched corrector of best design, $362.50, uncoated. Can also be used for f/2.5 Mak Newtonian prime focus setup. 8" f/11.8 set, $599.50. Standard and enhanced silver coatings available."
Sky Research
P.O. Box 2778, S.C.E.
Santa Cruz, CA 95063
408-426-3029

Versatile Refractor

"60 mm lens designed by Dr. David Rank...streamlined design, ideal for nature outings...durable lightweight aluminum...seven pounds...rugged...stability is obtained with 12-5/8" base...set on any flat surface...immediately ready for use...superior objective lens offers incredibly good definition over the entire field of view...$249 introductory price. 1.9 sec arc resolution...1.23° FOV w/15 mm RKE."
Edmund Scientific Co.
Barrington, NJ

2" Star Diagonal

"...Places the eyepiece in comfortable viewing position and has a large mirror which provides an unvignetted field when using wide-field eyepieces . . machined from solid aluminum and guaranteed [to have] perpendicularity to within one second of arc...custom-polished mirror is figured to 1/8 wave or better." $125. Adaptor to fit Celestron telescopes $19.75. Variable polarizing eyepiece $29.95.
Edmund Scientific Company
Barrington, NJ

"VISABLE" Guider

"Better than piggyback guidescopes," the visable guider takes "light from the periphery of the telescope's light cone near the prime focus and diverts to form a second (guide) image. Because the light is peripheral, the light to the main image (film) is not reduced." Guider arrives in kit form and includes instructions and parts to fit standard size 6" and larger Newtonians. Has "fine screw-operated focusing system...for better focusing control," free of camera-body interference, more comfortable guide positions, telescope still available for eyepiece observing without removing guider body. Kit: $175.00 each ppd. Information sheet available.
Thomas C. Venable
6111 Fifth Avenue
Pittsburgh, PA 15232

Compact Machine

"Machinex 5 is a multipurpose metalworking machine designed to provide R&D labs, Scientific labs, Instrument, and Prototype shops with a large variety of small part machining operations." Can do turning, facing, boring, threading, drilling, reaming, tapping, grinding, sawing, and polishing on machine steel, cast-iron, soft metals, as well as plastics and wood.

"Basic machine is a 5"-swing precision lathe with a 10" center distance...250-4000 RPM...1/4 h.p. motor...accessory steel column for vertical drilling...spindle nose threaded 1" x 16...collets up to 1/2" cap'y."

Basic machine $399.95. Large selection of accessories "makes its versatility almost unlimited."
American Edelstaal, Inc.
1 Atwood Avenue
Tenafly, NJ 07670

Holography Hype

"Because of visionary advances in laser technology, Dr. Gary Fisher of Man/Environment has developed and, via his marketing organization, is now offering for sale three-dimensional moving holgraphic images that actually appear to float in space..."

"...the promotional and advertising experts of the world have now been given yet another instrument of communication."

Amen.

Man/Environment, Inc.
P.O. Box 25591
Los Angeles, CA 90025

Letters

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Satisfied Reader

Dear Sir / TM4 added to my pleasure by arriving a few days ago. Getting it all read at once makes it a long time to wait for the next issue.

But let me assure you I've enjoyed all four issues — as proof I have sent in my renewal. Keep up the good work and don't worry too much about which articles to run. We love them all.

I have read Mr. Cox's material for years. I have had two occasions to write to him recently and I want you to know that I received prompt replies with some mighty good advice from him, all in a friendly and interesting style. Hope you can keep him interested as associate editor. He is certainly a good man for the job.

I followed the TM1 article on Cass scopes and worked out all the math, but was a bit hesitant about the design. Mr. Cox set me straight in a letter that arrived today. I will make some changes — he encouraged me to send in my design for comments. That is a real service that we really appreciate. Where else can we turn for helpful and willing advice?

Keep up the good work, Mr. Berry. We are already looking forward to the next TM. Our greetings and good wishes.

Alonzo Wierenga
45 Cass Street
South Haven, MI 49090

Interupted Project

Gentlemen / Some years ago I ground a 6" pyrex mirror and got to the polishing and parabolizing stage and then had to stop work on it. Is there anyone you know of who can finish the mirror for me? I would like to put it to work at long last; this is good country for astronomy.

Incidentally, the mirror was started about 1940 — then along came WWII.

Thanks in advance for any help you can give me.

Very truly yours,
Val Gates
Box 1031
Belen, NM 87002

Perhaps one of our readers will offer to finish your mirror for you.

-- R.L.B.

Baffled

Dear TM Editors / I am building a refractor using a 6" diameter telephoto lens made by Eastman Kodak for the USAF. My problem is light glare on the inside of the tube. I coated the inside of the tubes with flat black paint, but in daylight, the reflected light from the black surfaces is unbelievable. What can I do to eliminate this?

A. C. Sanowskis
Preso-Matic Lock Co.
3048 Industrial 33rd St.
Fort Pierce, FL 33450

Dear Mr. Sanowskis / Since you don't mention anything about baffles, we assume your tube is without them. Baffles are thin perforated disks of metal, thin wood, or cardboard fitted inside the tube that block light reflecting at low angles. You can determine the proper size openings in the baffles, as well as the optimum spacing, by drawing a full-scale cutaway of the tube, drawing in the light paths, then adding baffles to block all non-direct rays.

Ordinary flat black paint is not black enough for optical instruments; however, 3M makes a special optical black spray paint with a very rough surface. You can make a pretty good optical black yourself by mixing fine sawdust into ordinary flat black enamel.

From Genova

Vous recevrez un cheque de $8 comme souscription pour les numeros 5-6-7-8 de la Revue TELESCOPE MAKING.

Veuillez agreer, Monsieur, mes salutations les plus distinguees, et mes compliments pour votre remarquable Revue.

Menotti Lungonelli
Abit.: Via Tabarca 25 - 3
16147 Genova

Intensifier Query

Dear Richard / Saw you at Riverside last year; thoroughly enjoyed talking and looking through Mike Hatcher's 22" Newtonian with you. Since then, I've been

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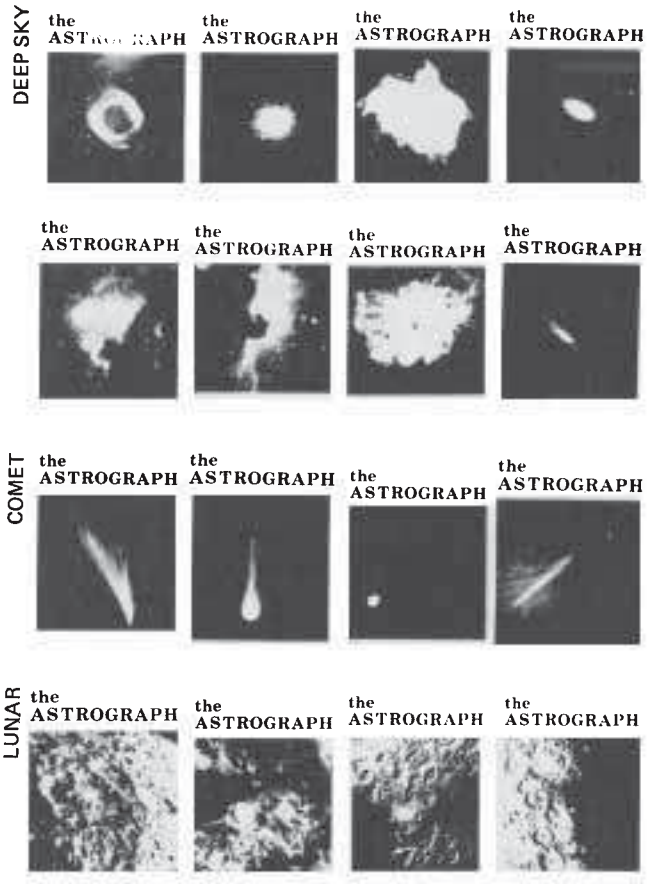

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Letters

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fortunate enough to pick up a zoom image intensifier tube (a Varian VLI-116) and am contemplating designing a scope — maybe a 10" — around it, but I haven't yet done any calculations on light gain vs. resolution. I'd appreciate any comments you or TM's readers might have on the telescope design or the use of intensifiers on them.

Clyde Edgar, Jr.
29403 Quail Run
Agoura, CA 91301

Dear Mr. Edgar / I've seen earlier-generation image tubes operating on professional telescopes (about 1974), and they're very impressive. Does anyone out there have a direct line to a source of good information, or practical experience, on applying image tubes to amateur telescopes? Write and let us know.

RLB

Mak. Club Address

Dear Sirs / I'm looking for more data on Maksutov optical systems. Can you give me the address of the "Maksutov Club Circulars" you mentioned in TM#1?

Dr. R. Levy
29 Bluffwood Dr.
Willowdale, Ont., Canada
M2H 3L4

Dear Dr. Levy / The Mak. Club Circulars are now part of **The Observer**, *bulletin of the Lehigh Valley AAS, available for $4 per year from George H. Mauer, Circulation Manager, R.D. 3, Box 140, Cooperburg, PA 18036.*

Glass for Jones-Bird

Recon Optical Glass can no longer supply glass blanks for the Jones-Bird telescope. Fortunately, a new supplier, Glass Brokers, Inc., 15032 Red Hill Avenue, Tustin, CA 92680, (tel.: 714-838-0730) will supply these blanks without a minimum charge.

Prices for BK-7 and F-2 blanks, grade A, fine annealed, FOB, are:

Set #1 -- 6" -- $4.50
Set #2 -- 8" -- $7.25
Set #3 -- 10" -- $11.25
Set #4 -- 12" -- $14.25
Set #5 -- 12½" -- $14.25

Any Other Old Scraps ....

A few years ago I made a six inch Newtonian reflector from two shelves out of the larder cupboard, half-shaft of a car, part of a car jack, bits of Meccano, plastic tops of coffee jars, and any other old scrap lying around. To show it could be done by any schoolboy with a little intelligence, I used only four tools to construct it: a tenon saw, pad-saw, wheelbrace with plenty of drills, and a screwdriver. The mirrors I purchased from a professional maker in 1975 for £20. I wrote an article about it for the **JBAA**, which has worldwide circulation among its 8,000 odd members. One member, living in Birmingham, Alabama, USA, saw it and it prompted him to make a telescope. He wrote me about it, and now we correspond regularly. He kindly sends me copies of TM.

The enclosed picture shows me with the telescope, Mark I. It has had a few improvements since the picture was taken. In the background is my low-cost homemade rotating observatory containing my eight and half inch equatorial.

I wonder if you would be interested in articles on either or both, or are they too small for your readers? I have before me TM#3 which is devoted to LARGE small telescopes!

Yours Truly,
Reg Spry
60 Windsor Road,
Selsey P020 0AU
Sussex, England

Dear Mr. Spry / I am looking forward to seeing your article and pictures about this cleverly contrived telescope and observatory. Now, about that observatory, how does it rotate?

■

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photo by Jack Newton

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